Bottone

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GUIDE TO ELECTRIC LIGHTING

A GUIDE

TO

ELECTRIC LIGHTING

FOR THE USE OF

HOUSEHOLDERS AND AMATEURS

BY

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CHAPTER I

1. THE applications of *Electricity* to the furtherance of the conveniences and comforts of civilised life have become so varied and so important, that it behoves all who lay any claim to an intelligent knowledge of their surroundings to acquire some cognizance, however slight, of the laws which regulate these applications, and of the apparatus and instruments by means of which the desired results are obtained. In another work* the author has treated of the application of electricity to signalling purposes; it is the scope of this book to show by what means electricity can be made subservient to the purposes of illumination and the transmission of motive power.

2. Without entering deeply into the various theories as to what electricity is, it will be sufficient for us to

* "Electric Bells." Whittaker & Co.

state that electricity is a mode of motion in the minute molecules or atoms which constitute all known bodies. Whether this motion be rotary or undulatory we have no certain means at present of knowing; but by analogy with the kindred phenomena of sound, light, and heat, the probabilities are that the motion is of an undulatory nature. The means of evoking the phenomena which we know as electricity are many and varied. They consist in mechanical disturbances, such as friction, percussion, and pressure; or the application of heat and cold; the action of magnets on moving bodies; and lastly the influence of that subtle motion which we know under the name of chemical action. Although it is perfectly possible to produce light or motion by means of the electricity generated in any of these manners, yet hitherto application on a practical scale has been made only of the last two modes, viz., *motion before the poles of a magnet*, and *chemical action*. It will be with these two latter methods of calling forth electric currents, therefore, that we shall chiefly deal here.

3. The Voltaic battery, with its hundred and one modifications, consists essentially of two elements, one of which is acted on by an acid or similar body; and the other, which being unacted on by the acid, serves to collect and transmit to the outer circuit the elec-

tricity generated by the action of the acid, etc., on the first mentioned. It must not be imagined that electricity is a *thing*, and that it has any existence *per se;* for although in some of its effects it may be likened to a flow of water or steam, yet it is more nearly related to the undulatory motion set up by a rush of wind across a field of corn, or by the shaking of a long sheet held by its four corners, than to the actual flow of any material body. The first form of Voltaic battery, as is well known, consisted in a pile of zinc and copper discs alternated with smaller discs of moistened flannel. The flannel was saturated with a solution of common salt, and on being placed between the copper and zinc discs acted chemically on the zinc, and in so doing gave rise to electricity: which, however, did not give evidence of its existence until the zinc and copper discs were united by means of a wire of copper or some other conductor. Herein lies the peculiarity of what is called *current electricity:* when we set up a strain or stress in any of the manners above mentioned, the strain tends to equalise itself and return to the point of least tension; and if this is effected through a conductor returning to the point at which the strain or stress is set up, the effect resulting from this attempt at restoring equilibrium gives rise to what we know as the *electric current.*

Without making any profound study of the constructional details of the many forms of battery now in use, a few of the more important will now be described, choice being made of those which, by reason of their efficiency or some other peculiarity, are more particularly adapted to electric lighting and the transmission of power.

4. The first which claims our attention is the *Grove* battery. This consists in a plate of zinc, well amalgamated,* generally taking the form of the letter U, standing in a square glass or glazed earthenware cell between the limbs of which stands a smaller porous cell. In this cell, depending from a cross-bar of wood, is a sheet of platinum. In the outer compartment, along with the zinc is placed a dilute solution of sulphuric acid, consisting of one part of sulphuric acid, Sp. Gr. 1·840, and twelve parts of water. In the porous cell, along with the platinum is placed strong nitric acid, of the specific gravity 1·42. The chemical action set up in this battery is shown by the following equation, in which Zn stands for zinc, N for nitrogen, O for oxygen, H for hydrogen, and S for sulphur. In the zinc compartment we have

$$Zn + H_2SO_4 = ZnSO_4 + H_2;$$

* Amalgamated—saturated with metallic mercury.

which means that in the presence of zinc the sulphuric acid parts with its hydrogen and seizes upon the zinc to form sulphate of zinc. This hydrogen, if there were no nitric acid in the way, would be carried along by the current of electricity generated, till it reached the platinum plate; and there, by adhering to its surface, would greatly impede the reception and transmission of the electricity by this plate. But on reaching the porous cell containing the nitric acid it passes through the pores thereof, and in the presence of the nitric acid effects the change illustrated by the annexed equation:—

$$H_2 + 2HNO_3 = 2H_2O + 2NO_2.$$

From this it results that no free hydrogen reaches the platinum plate; consequently this latter is always ready to receive and transmit the electrical current set up, so long as any free nitric acid remains in the porous cell.

Owing to this the Grove cell is a very constant form; that is to say, the intensity of its action does not vary so long as the supply of sulphuric acid and nitric acid is kept up.

Figure 1 illustrates the form usually given to the *Grove* cell. Although the Grove cell constitutes a very powerful form of battery, yet it has many draw-

backs. In the first place, the price of platinum is very high; secondly, under the influence of the hydrogen the nitric acid is split up, and noxious fumes of nitrous acid are given off which are highly deleterious and

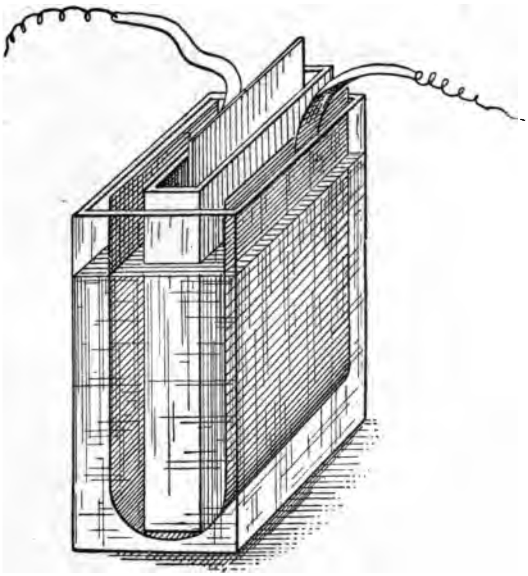

FIG. 1.—GROVE CELL.

give rise, if respired, to hæmoptysis; thirdly, unless the cells are made of an inordinate size, the quantity of fluid they will hold is only sufficient to supply current for from six to eight hours at most; fourthly,

strong nitric acid, being an extremely acid and corrosive liquid, is very disagreeable and dangerous to handle.

5. The next form of battery (which is closely allied to the Grove) is the *Bunsen*. This consists in a block

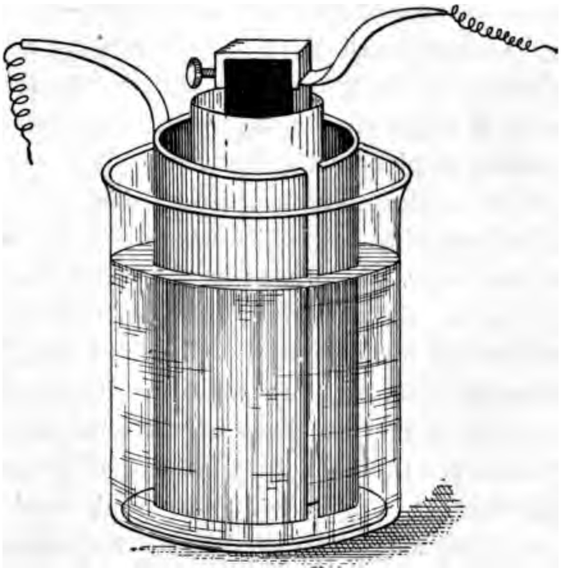

FIG. 2.—BUNSEN CELL.

of gas carbon (otherwise known as graphite or retort-scurf) standing in a cylindrical porous cell surrounded by a cylinder of amalgamated zinc; the whole being contained in a glazed earthen or glass jar. This is illustrated in Figure 2.

The chemical action which takes place in the Bunsen cell is precisely similar to that which we have already noticed in the Grove; and the advantages and defects are similar, except in two points: first, *graphite* is extremely cheap and therefore the prime cost of the battery is very much less; secondly, owing to the irregularities of the graphite or carbon, the surface presented is larger than that presented by an equivalent sheet of platinum, consequently the battery is rather more efficient in action, size for size.

6. The form of battery which next claims our attention is the *Fuller*. In this, as in the two former, we have a porous cell standing in an earthen vessel. In the porous cell stands a stout cylinder of zinc, itself well amalgamated, and surrounded at its lower extremity with mercury to keep up the amalgamation. The porous pot itself should be painted all round the outside, with the exception of a strip of about an inch wide extending along its whole length, with hot melted paraffin-wax. This is to prevent the fluids permeating the cell too readily. On the outside of the porous cell, standing in the earthenware or glass jar, is a large plate, or in some cases a cylinder, of graphite. Up to this point the Fuller bears a considerable resemblance to the Bunsen. It is, however, in the fluids used for charging that the difference chiefly obtains. In the

Bunsen cell we have dilute sulphuric acid acting on the zinc, and strong nitric acid in contact with the carbon or graphite, to absorb the hydrogen generated. In the Fuller cell either no acid at all is used along with the zinc, or else a dilute solution of chloride of zinc takes its place; but usually plain water is sub-

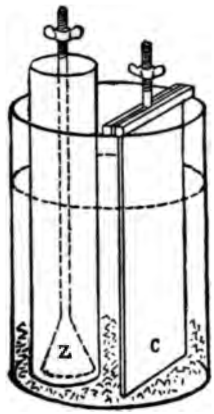

FIG. 3.—FULLER CELL.

stituted. To do away with the noxious fumes of nitrous acid which are generated when nitric acid is employed, a saturated solution of bichromate of potash, or, better still, of chromic acid acidulated with about one sixth of its bulk of sulphuric acid, is employed. This battery, though not so powerful as the two forms previously described, has great merit in point of con-

state that electricity is a mode of motion in the minute molecules or atoms which constitute all known bodies. Whether this motion be rotary or undulatory we have no certain means at present of knowing; but by analogy with the kindred phenomena of sound, light, and heat, the probabilities are that the motion is of an undulatory nature. The means of evoking the phenomena which we know as electricity are many and varied. They consist in mechanical disturbances, such as friction, percussion, and pressure; or the application of heat and cold; the action of magnets on moving bodies; and lastly the influence of that subtle motion which we know under the name of chemical action. Although it is perfectly possible to produce light or motion by means of the electricity generated in any of these manners, yet hitherto application on a practical scale has been made only of the last two modes, viz., *motion before the poles of a magnet*, and *chemical action.* It will be with these two latter methods of calling forth electric currents, therefore, that we shall chiefly deal here.

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increased by placing graphite plates on both sides of the zinc; and the duration of its action may be prolonged by the addition of about 5 per cent of chlorate of potash to the exciting fluid. If a number of cells are employed, it will be very convenient to have the elements fitted with a lifting arrangement by means of a ratchet and pawl. The chief defect of this battery depends on the fact that during the action of the sulphuric acid on the zinc, since the hydrogen generated is immediately seized upon by the solution, there is absolutely no intestine motion in the fluid contained in the cell; the consequence is that the sulphate of zinc formed in the proximity of the zinc plate remains there and after a time prevents the farther action of the sulphuric acid upon the zinc. The result of this is that the battery ceases working after about a three hours' run.

Figures 4, 5, and 6 show the forms generally given to the bichromate battery.

8. We have now to consider a form of battery that from the extremely long time in which it will remain in action, provided too long or too frequent demands be not made upon its strength, is convenient where a small current at short intervals (which, however, may extend over a period of a year or eighteen months) is required. The cell in question is known as the

Leclanché. This consists in a rod or block of carbon standing in a porous cell and packed round so as to fill up the said cell with a mixture of about equal parts of coarsely powdered black oxide of manganese and graphite. (In order that the pores may not be stopped up it is necessary that the particles of carbon and manganese be in no wise smaller than grains of rice.) The porous cell itself stands in a square glass jar, in one corner of which is placed a rod of amalgamated zinc. To set this in action the porous cell and the glass jar are filled to about three quarters of their capacity with a half-saturated solution of chloride of ammonium (sal-ammoniac). As this latter solution has a great tendency to creep up the sides of the jar and crystallise thereon, greatly to the detriment of the cell's action, it is customary to dip the upper portions of both porous cell and glass jar either in melted paraffin-wax or in melted pitch, both of which substances effectually cure the creeping tendency. Sometimes the relative positions of the carbons and zincs are changed; that is to say, the zinc rod is placed in the porous cell along with the chloride of ammonium solution, while a large carbon plate or plates, packed as before with a mixture of black oxide of manganese and graphite, are placed outside the porous jar in the glass jar. In that form known as the Agglomerate

Leclanché no porous cell is made use of. The carbon plate is surrounded on either side by blocks of material made by compressing strongly together the mixture of black oxide of manganese and carbon along with a little shellac to cause it to bind, and the zinc rod is re-

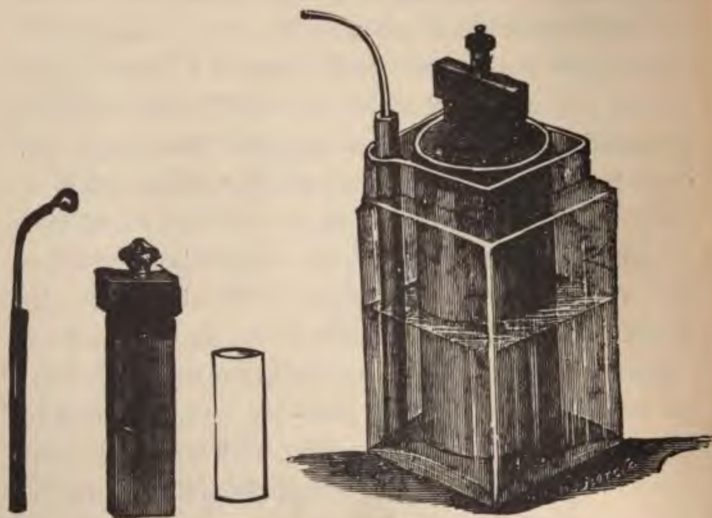

FIG. 7.—LECLANCHÉ CELLS.

tained in its place, at a little distance from this kind of sandwich, by means of India-rubber bands. The whole combination is then immersed in a glass cell containing a solution of sal-ammoniac. In work these three forms differ very little; they have the great advantage

that absolutely no action takes place unless the circuit is closed, and therefore no consumption of zinc or other material takes place unless the battery is doing useful work. For this reason, also, they can be put aside for a very lengthy period without deterioration taking place, and are ready to give their full current at

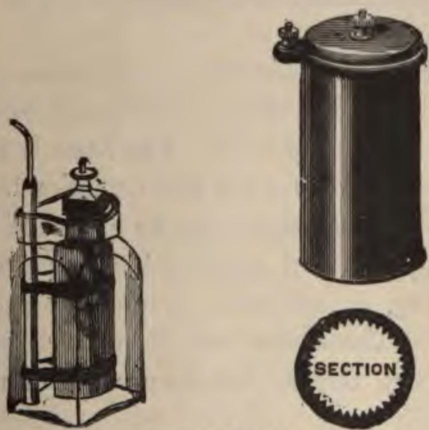

FIG. 8. LECLANCHÉ CELLS. FIG. 9.

a moment's notice. On the other hand, they polarise quickly; that is to say, the hydrogen generated by the action of the water on the zinc is not immediately got rid of, so that the strength of the battery soon runs down, and in twenty minutes after the circuit is closed becomes almost nil. But if allowed to stand for a short time, the black oxide of manganese gives up a

portion of its oxygen to the hydrogen, reconverting it into water, and the battery recovers its strength. It is therefore eminently adapted for short work at repeated intervals, such as bell-ringing, lighting small lights for a few minutes to see the time by a watch at night or to examine the contents of a cupboard, etc. The modifications of the Leclanché cell are shown in Figures 7, 8, and 9.

9. Another form of cell, closely allied to the Leclanché, which was brought into public notice by Dr. Gassner, is the "*dry*" cell. The name is a misnomer, for the cell is not dry but moist. Since, however, the contents are sufficiently firm to allow the cells being turned upside-down or placed in any position without spilling, it sufficiently denotes the peculiarity of the cell. The reader may make for himself a very efficient dry cell by following the directions given below.

Procure a cylinder of zinc about 3 inches in diameter, 6 inches in height, and $\frac{1}{25}$ of an inch thick. Solder a zinc bottom to it, so as to make an upright pot. Now make a mixture of

Plaster of Paris..................	25	parts
Ammonium chloride..............	10	"
Water..........................	55	"

Lay a coating of this mixture on the bottom and round the sides of the zinc cell to the thickness of a quarter of an inch, leaving a space of about one inch round the top edge uncovered. Let this set. When firm enough to take the impression of the finger without sticking to it, place a carbon plate (graphite) about 6½″ long, 2¼″ wide, and ⅜″ thick, fitted with a terminal, in the centre, and fill in round the sides, by ramming pretty tightly, with a mixture of

Powdered graphite................	75	parts
Manganese oxide.................	10	"
Chloride of zinc..................	5	"
Chloride of ammonium...........	10	"

and sufficient water to make a stiff paste. This must not extend beyond the layer of plaster of Paris laid round the inside of the zinc pot. Make the surface level, and then fill up flush with the edge of the zinc pot with melted pitch. Solder a stout copper wire to the outside of the zinc vessel, to serve as a connection or terminal, and then paste on the outside of the zinc jar a layer of stout brown paper, to prevent accidental metallic contact with other conductors. It will be seen from the above description that the "dry" cell is very similar in construction to the Leclanché, the

chief point of difference being the substitution of a plaster-of-Paris paste for the porous cell, and a moist magma of carbon, manganese, and chloride of ammonium for the chloride of ammonium solution. In action it closely resembles the Leclanché. Its portability, and some other peculiarities which will be noticed later on, commend it for use in certain cases in which the Leclanché would be less suitable. Figure 10 represents the usual form given by makers to the dry cell.

FIG. 10.—DRY CELL (GASSNER).

10. The reader having now formed some conception of what a battery is, it will be well for him to consider the mode in which it works, so as to be able to form an idea of the relative adaptability of the different forms for the particular purposes to which they may be

applied. When an acid acts chemically on zinc, a certain strain or stress is set up which, if a conductor is placed in circuit so that the strain can relieve itself, produces in its turn a current. Now the strain set up is called *electro-motive force*, or E. M. F. as it is abbreviated, and this is usually measured in *volts*,* this being approximately the E. M. F. set up by the Daniell cell.† The E. M. F. is entirely irrespective of the size of the cell used; it depends solely on the nature of the acid and of the elements employed in that cell. The current, which is the flow of electricity in the entire circuit, is dependent on two factors—first, the *electro-motive force*, and secondly, the *resistance* which there is in the circuit. By resistance, electricians understand the opposition which the electricity finds to its passage. As in a former example we likened the flow of electricity to the undulatory motion set up in a cornfield by the wind, so we may liken the resistance in circuit to an increased stiffness in the straws supporting the ears of corn: and we could imagine that great resistance would be presented to any such undulatory motion were the stems

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* Volt—the recognised measure of electrical pressure.

† The Daniell cell consists in a sheet of copper surrounding a porous cell in which stands a rod of zinc, sulphate of copper being placed near the copper, and dilute sulphuric acid along with the zinc.

of the corn made of rigid steel. Or we may liken the electro-motive force to the energy expended by a man working at a pump connected to which may be adjusted pipes of different diameters, the larger ones opposing naturally less resistance to the passage of the water pumped. Hence with the smaller pipes opposing a great resistance, a small current only of water could be obtained; whereas the pipes of larger bore, opposing less resistance, would admit a much larger flow of water. It has been found, as the result of careful experiment, that the amount of current obtainable from any given electro-motive force is equal to the electro-motive force divided by the resistance. This is formulated in "Ohm's law" (from the name of the propounder) as

$$C = \frac{E}{R};$$

where C stands for current, E for electro-motive force and R for the resistance.

At first glance these three letters seem to afford but little insight into the adaptability of any source of electricity to do any given work; but in point of fact, when we have given a value to the E. M. F., to the resistance, and to the current, they enable us to solve

at once any problem of this nature which may present itself for our consideration. In the same way as we measure the energy in a steam-engine by the pounds pressure or by foot-pounds, so we measure the E. M. F. by *volts*. The resistance is measured in *ohms*, the ohm being the opposition or resistance presented by a column of mercury one square millimetre in section and 1·063 metres in height. For the purpose of experiment it will be sufficient to say that this is nearly equal to the resistance presented by one foot of No. 36 B. W. G. iron wire, or by 5 feet of No. 36 B. W. G. copper wire. The measure of current (very similar to gallons flowing, in speaking of water) is called the *ampère*, and this is the quantity of current which an E. M. F. of 1 volt can force through a resistance of 1 ohm. This can be shown graphically by the following equation :—

$$\frac{\text{1 volt}}{\text{1 ohm}} = \text{1 ampère.}$$

It will be evident from this that, provided the stress or strain called E. M. F. can be kept up, the current in ampères can be varied to almost any desired extent by varying the resistance placed in circuit. For example, let us suppose that we have an E. M. F.

of 1 volt, with a resistance in circuit of ·01 of an ol what will be the current? By Ohm's law we $\frac{1}{\cdot 01}$ = 100 ampères. That is to say, it is possibl obtain a current as large as 100 ampères witl E. M. F. of only 1 volt, provided the entire resist in circuit do not exceed $\frac{1}{100}$ of an ohm. In manner with the same E. M. F. of 1 volt, if we h resistance in circuit of 100 ohms, we shall get onl of an ampère, since $\frac{1}{100}$ = ·01 ampère. Now, c batteries previously described, the one that ha highest E. M. F. is the bichromate or chromic-aci (§ 7), which gives a pressure of about 2 volts. resistance of this cell, owing to the nature of th used and to there being no porous partition i way, is very low, not exceeding, in a cell having 4 inches square, ·08 of an ohm; so that the c which this cell can give on short circuit (that say, with no other but its own internal resi is as high as 25 ampères. A table of the E. internal resistance, and current given by the ries previously described is appended to ena reader to judge of the capacities of several fo batteries.

11. Table of the *E. M. F.* in *volts*, *current* in *a* and *resistance* in *ohms*, of the most useful batter

Name of Cell.	Positive Element.	Negative Element.	Exciting Fluid.	Depolarising Fluid.	E.M.F. in Volts.	Internal Resistance in Ohms.*
Bunsen	Zinc	Graphite	Sulphuric acid dilute	Nitric acid	1·8	·08 to ·11
Do.	"	"	"	Chromic acid	1·8	0·1 to 0·12
Chromic acid, single fluid	"	"	Sulphuric acid and chromic acid dilute, mixed	None separate	2·2	·016 to ·08
Daniell	"	Copper	Zinc sulphate solution	Copper sulphate solution	1·079	2 to 5
Fuller	"	Graphite	Water	Potash bichromate and sulphuric acid	2·0	0·5 to 0·7
Gaiffe	"	Silver	Zinc chloride	Silver chloride	1·02	0·5 to 0·6
Grove	"	Platinum	Sulphuric acid dilute	Nitric acid	1·96	0·1 to 0·12
Lalande-Chaperon	"	Copper or iron	Caustic potash solution	Oxide of copper	0·98	1·30
Latimer-Clark	"	Pure mercury	Sulphate of mercury	None separate	1·457	0·3 to 0·5
Leclanché	"	Graphite	Ammonium chloride sol.	Manganese dioxide	1·6	1·13 to 1·15
Maiche	Zinc scraps, in bath of mercury	Platinised carbon	Common salt solution	None separate	1·25	1 to 2

* The resistances were measured in cells standing 6″ × 4″.

Name of Cell.	Positive Element.	Negative Element.	Exciting Fluid.	Depolarising Fluid.	E.M.F. in Volts.	Internal Resistance in Ohms.*
Marie-Davy	Zinc	Graphite	Sulphuric acid dilute	Paste of sulphate of mercury	1·52	0·75 to 1
Niaudet	"	"	Common salt solution	Chloride of lime	1·0 to 1·6	5 to 6
Poggendorff	"	"	Saturated solution of potash bichromate and sulphuric acid	None separate	1·98	·001 to ·08
Schanschieff	"	"	Mercurial solution	"	1·56	0·05 to 0·75
Skrivanow	"	Silver	Caustic potash	Chloride of silver	1·5	1·5
Smee	"	Platinised silver	Sulphuric acid dilute	None	0·47	0·5
Walker	"	Platinised graphite	"	"	0·66	0·4
Warren de la Rue	"	Silver	Sal-ammoniac solution	Silver chloride	1·03	0·4 to 0·6

* The resistances were measured in cells standing 6″ × 4″.

12. We noticed that when a battery is at work, hydrogen is generated by the action of the fluid upon the zinc; and that this hydrogen is carried along with or by the flow of electricity from the zinc plate to the other, which is the collecting or receiving plate of the electricity generated. This hydrogen, by collecting

around the receiving plate, soon prevents any farther electrical action: and it is this effect, known as *polarisation*, which for so long a time prevented the extensive use of batteries as generators of electricity for any purposes in which currents of lengthened duration were desirable. The substances which are now employed to dissipate or otherwise to get rid of this obnoxious hydrogen are either such as act mechanically by allowing the hydrogen to escape—as, for instance, finely divided platinum on the collecting plate of the Smee's battery—or else those which, by containing and giving up readily a large quantity of oxygen, convert the hydrogen into water. Such bodies are chromic acid, nitric acid, black oxide of manganese, etc. Although it is possible by these means to increase the duration and enhance the constancy of batteries, yet there are certain considerations which will ever restrict the use of batteries to cases in which comparatively short duration of effects is required. The first consideration is that of price. In all modern forms of batteries we are consuming zinc to produce our energy, and zinc costs at least six cents a pound; and although the energy procurable from a pound of coal is not so great as that obtainable from a pound of zinc, still the comparative lowness of the price of coal turns the scale in its favour. Again, unless cells of a very large

size are used, so as to contain a large quantity of zinc and of the acids employed, the materials are soon exhausted; and this necessitates labour in recharging and in renewing the zincs at frequent intervals: and this labour must be skilled labour, which adds to the expense. The use of the table given at § 11 becomes evident when we apply it to a practical case; and in order to accustom the reader to working out his own calculations as to the number and nature of the batteries required to perform any given work, the following examples are subjoined.

Let us suppose we have to light a lamp which requires 1 ampère of current to pass through it to produce its due amount of light; the resistance of the lamp being 25 ohms. Let it be required to do this work with the smallest possible number of cells. What cells and what number of them will be required?

Since we can increase the E. M. F. of cells only by coupling a number together in series—that is to say, the zinc of the one cell to the carbon (or copper) of the next—and since no single cell has an E. M. F. sufficiently high to force 1 ampère of current through a resistance of 25 ohms (irrespective of its own internal resistance, which must also be taken into account), it follows that we must employ a number of cells. On looking over the table we find that the cell which has

the highest E. M. F. is the single-fluid chromic-acid cell. The E. M. F. of this cell we find to be about 2 volts, so that 12½ such cells will be needed to give the requisite five-and-twenty volts to obtain 1 ampère through the resistance of 25 ohms in the lamp; for, according to Ohm's law,

$$\frac{E}{R} = \frac{25}{25} = 1,$$

and this is not allowing anything for the internal resistance of the cells themselves. When we couple up a number of cells *in series*, the resistance becomes additive; in other words, *we must add the resistances of each of the cells together;* and since the resistance of one cell of the chromic-acid type is ·08 ohm, and as we cannot split a cell, we must employ 13; so the equation comes out thus:—

$$\frac{E}{R} = \frac{2 \times 13}{(\cdot 08 \times 13) + 25} = \frac{26}{26\cdot 04} = 0\cdot 998;$$

which is sufficiently near 1 ampère to serve our purpose. Therefore the smallest number of chromic-acid cells that could be employed to light such a lamp would be 13 cells, with a duration of about 3 hours, as

we have seen that the chromic-acid cell polarises in about that time.

Now let us suppose that we were contented with a momentary light at intervals and wished to employ for the purpose Leclanché cells. What number will be required to furnish the requisite amount of current to feed the said lamp? The Leclanché cell has an E. M. F. of only 1·6 volts, and the resistance of the cell of medium size is 1·13 ohms. Hence we see that a large number of cells will be needed; and since the internal resistance of the cells themselves is so great, it will be necessary to couple some of them in parallel * in order to diminish the internal resistance, which diminishes in proportion to the number of cells joined together *in parallel*, the E. M. F. remaining the same. For example, a given Leclanché cell having an E. M. F. of 1·6 volts and an internal resistance of 1·13 ohms if coupled in parallel (or tandem fashion, as it is sometimes called) to another precisely similar cell would still give an E. M. F. of 1·6 volts; but the internal resistance in consequence of the surface of the plates being doubled would fall to 0·565 of an ohm. Therefore if we were to take 50 Leclanché cells and couple

* Cells are said to be coupled in parallel when all the zincs are connected together to form one large zinc, and all the carbons coupled together to form one large carbon.

them in 25 sets in series of two in parallel with each other, we should get

$$\frac{E}{R} = \frac{25 \times 1{\cdot}6}{(25 \times 0{\cdot}565) + 25} = \frac{40}{39{\cdot}125} = 1{\cdot}02,$$

or a trifle over 1 ampère: and this is sufficient to meet the requirements of the case.

CHAPTER II

13. It is now time to direct our attention to another device whereby currents of electricity can be produced. We refer to the *dynamo*. As a full description of the principles on which this instrument is based has been already given in another work,* it is not proposed to enter deeply into details in this place; a sufficient insight, however, will be given to enable the reader to understand its working, and to select that form most suited to his particular requirements. The dynamo consists essentially of a magnet, either permanent or temporarily excited, near the poles of which can be moved (generally rotated) a piece or pieces of iron around which layers of wire are coiled, known as an "armature." As we have previously noticed, when any body is moved before the poles of a magnet, in that portion where the

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* "The Dynamo, how made and how used."

magnetic intensity is greatest (known technically as the "field" of a magnet), if the body cuts the lines of force in that field, or passes from points of greater to those of lesser intensity, or *vice versa*, electrical currents are set up in the rotating body, in a direction at right angles to the lines of force of the magnetic field. In dynamos as constructed at the present day the magnets which set up these lines of force or "field" are not permanent magnets, but simply masses of soft iron around which are coiled layers of copper wire insulated * from one another and which become, under the influence of the currents of electricity that are sent round them, powerful magnets. In order to collect the currents generated in the armature or moving portion of the dynamo, this also is coiled with wire, generally in several sections, and the opposite ends of each section are brought out and connected to metallic bars attached to a hub rotating on the spindle which supports the armature. From these, which are known collectively as the "commutator," the currents generated are picked up by two metallic bundles of sheet brass or copper, or copper wire, known as the "brushes." From these the current is distributed to the outer circuit. In order to supply

* Insulated—cut off from electrical contact with any other body. Wire is insulated by being wrapped with cotton or silk.

the current to energise the masses of soft iron and convert them into powerful electro-magnets, advantage is taken of two facts: the first being that large masses of iron during the process of hammering and forging acquire a small amount of residual magnetism; and secondly, that it is possible to shunt off or divert a portion of the current flowing along any conductor by connecting that conductor with another at any two points along its length.

14. Dynamos may be divided into four great classes: firstly, those in which permanent magnets alone are used to set up the magnetic field in which the armature rotates; secondly, those in which electro-magnets are used, but in which the current which excites the magnetism in them is supplied from an external source; thirdly, those in which the entire current generated in the armature passes round the field-magnets to excite them, and completes its circuit through the lamps, etc., before returning to the dynamo; and fourthly, those in which a portion of the current is diverted from the outer circuit by means of coils of fine wire, and serves to excite the field-magnets without interfering with the main current which feeds the outer circuit, consisting of lamps, etc.

15. Of the first class we have the old-fashioned

magneto machine so much used for medical purposes and illustrated in Fig. 11. This consists, as the engraving shows, of a permanent magnet before the poles of which rotates a pair of bobbins wound with one continuous length of insulated copper wire, affixed to a cross-piece through which runs a spindle. At one end of the spindle is the *commutator*, or current-collector, to which the two free ends of the wire coiled

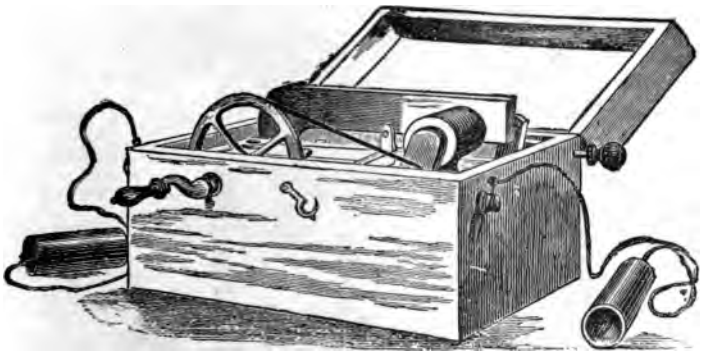

FIG. 11.—MAGNETO MACHINE.

on the bobbins are attached, and which is pressed upon by the spring or springs which serve as brushes. At the other end is a pulley or cogged wheel, either of which can be driven by a small handle and winch, by means of which a rapid rotary motion can be imparted to the spindle carrying the bobbins. Machines precisely similar in principle to this, which is known as the

magneto-electric machine, have done good service in illuminating lighthouses, etc.; but owing to the diffi-

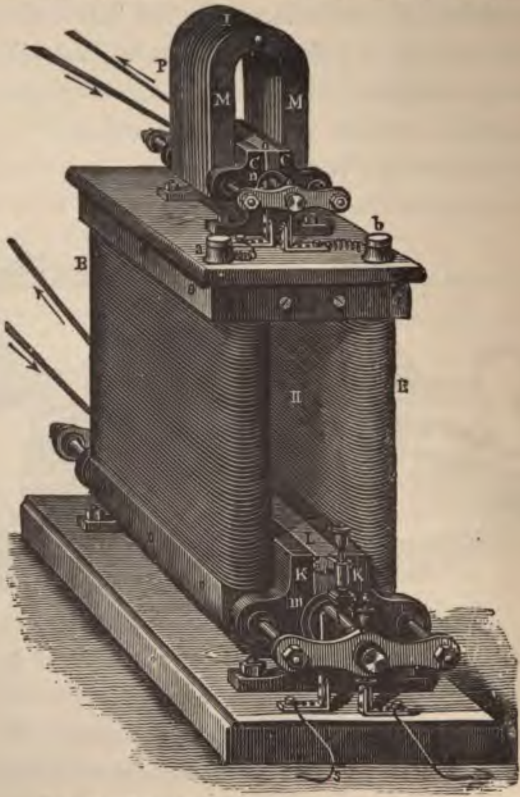

FIG. 12.—WILDE'S DYNAMO WITH ELECTRO-MAGNET.

culty of making large permanent magnets of great power, and the comparative ease with which they lose

their power by jolts, jars, and vibration, their use has been almost discontinued, except for small medical machines and for exploders for mine-fuses, in favour of dynamos with electro-magnets.

16. Of the second class we have all such machines in which no permanent magnets are employed, but in which the magnetism is imparted to soft iron cores coiled with wire, through which currents of electricity from an independent source are caused to flow. From this peculiarity these machines are known as "separately excited" dynamos, of which we illustrate one known as "Wilde's" (Fig. 12).

If the current in these separately excited machines be so collected by the commutators and brushes as to be sent continuously in one *direction*, the machine is said to give *unidirection* current; if, by reason of a difference in the form of the collector or commutator, the currents are picked up and transmitted to the outer circuit as they are generated, first in the one direction and then in the other, they are called Alternators. The older form of the Siemens Alternate-current Machine is shown in Fig. 12*a*, and the more modern form of the Mordey Alternator is illustrated in Fig. 13.

In these latter machines the current set up in a small dynamo, either of the permanent-magnet or any

other class (provided it give a direct continuous current and not an alternating one), is collected and passed through the coils which surround the field-magnets of

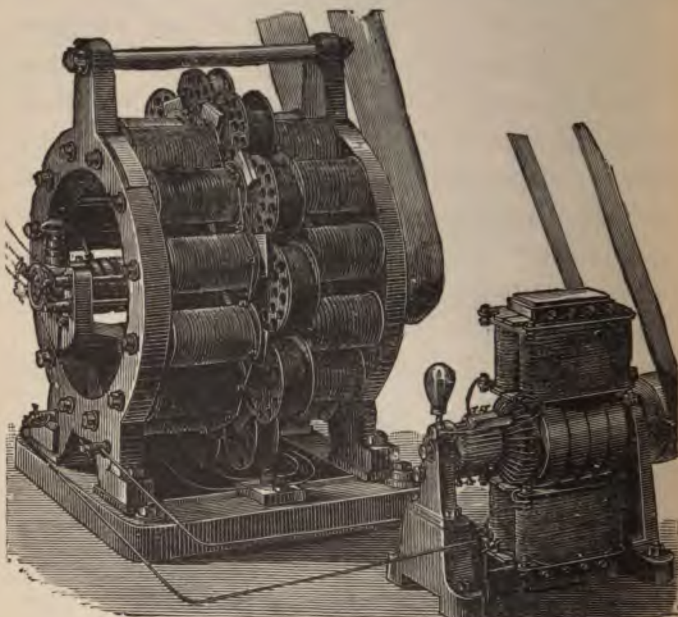

FIG. 12a.—SIEMENS ALTERNATOR.

the main machine, its sole purpose being to energise the said fields and convert them into powerful magnets. The armature, with its peculiar commutator consisting of two plain rings insulated from each other, but each

connected to the opposite ends of the armature wires, rotates between these powerful electro-magnets.

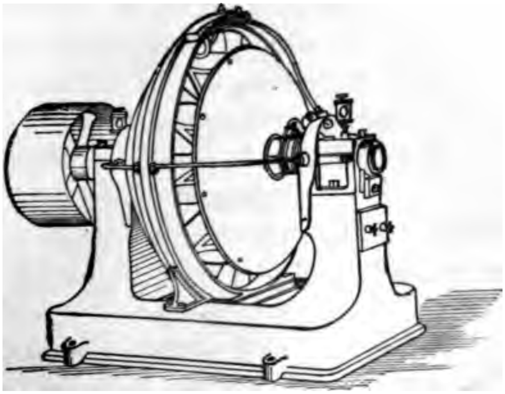

FIG. 13.—MORDEY'S ALTERNATOR.

17. To machines of the third class belong all such as derive their energising force directly from their own armature. If we coil a horseshoe of iron with insulated copper wire and pass a current of electricity around the coils, we shall find that as long as the current passes, the horseshoe will become powerfully magnetic; losing almost entirely its magnetism with the cessation of the current. If now we arrange a coiled armature so that it can be rotated between the poles of such a horseshoe, and if we impart to the horseshoe a small amount of magnetism either by placing it in the earth's magnetic meridian, or by tap-

ping it, or by having previously excited it by means of a battery, we shall find, on rotating the armature, that a small current of electricity is set up: and if we lead this current, by means of appropriate connections between the brushes pressing on the commutator and wires, to the coils surrounding the said horseshoe, the small current thus set up in passing round the horseshoe will increase the magnetism thereof, which in its turn will increase the current set up in the armature, and that again will exalt the magnetism set up in the horseshoe, and so on by cumulative effects, until the iron has been rendered as powerfully magnetised as it is capable of becoming, and the armature is giving the largest amount of electricity which it is able to supply at the given speed at which it is being rotated. Since it is not essential that *wire* should form the connection between one of the brushes and the field-magnet wire of such a machine, provided there be conductors to carry the current and complete the circuit from the armature to the field-magnets, it is evident that lamps, motors, or any other desired work may be placed in the circuit and receive and convey the current thus set up. Machines acting in this way are known as "series" dynamos, from the fact that the current passes in *series* from the armature through the outer circuit round the field-magnets and back again

to the armature. A typical dynamo of the "series" type is that represented at Fig. 14.

The disadvantage connected with this class of dynamos is that the resistance of the outer circuit cannot be greatly varied without impairing the efficiency of the machine. If the resistance of the outer circuit be too great, the field-magnets do not receive sufficient current round their coils, do not become sufficiently magnetised, and consequently the machine ceases to

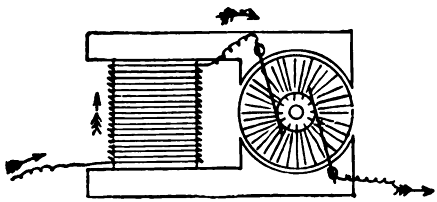

FIG. 14.—SERIES DYNAMO.

supply current. On the other hand, if the resistance in circuit be too low, the field-magnets become too powerfully magnetised, too much current is generated, and the insulated wires, both of the armature and of the field-magnets, become heated, owing to the passage of so large a current through them, and the cotton, etc., which serve to insulate the said wires risk being burnt up. In those cases, however, in which a steady current has to be kept up through an unvarying re-

sistance, or in which the resistance varies within small limits, the "series"-wound dynamo will be found extremely efficient and simple in construction.

18. The fourth class of machines is that in which a portion only of the entire current generated in the armature is diverted or *shunted* to feed or magnetise the field-magnets. For this reason these machines are known as "shunt" dynamos. In the construction of such a dynamo, advantage is taken of the fact that it is possible to magnetise a piece of iron to the same degree either by passing round it *once* a current of 1 ampère, or by passing a current of $\frac{1}{1000}$ of an ampère 1000 times round it; so that if it were necessary to pass a current of 100 ampères through a wire making only one coil round a piece of iron, to give it a certain stated magnetic intensity, this end could be attained equally by passing a current of 1 ampère through a wire making one hundred coils round the said piece of iron. Hence it is evident that if, instead of sending all the current generated by the armature of a dynamo round a few coils wound on the field-magnet cores (as in the series dynamo), we divert or shunt off (see § 13) a portion only of this current from the main circuit, and increase the number of coils on the field-magnets in due proportion, we shall be able to energise the field-magnets to the same point, while leaving the

current in the main circuit but slightly diminished. A typical shunt-wound dynamo is depicted at Fig. 15. The fact that any increase in the external resistance (that is, the working circuit, where the lamps, etc., are placed) compels more current to circulate round the field-magnets, and therefore makes them more powerfully magnetic, causing the armature to give more current, renders a shunt-wound dynamo to a certain

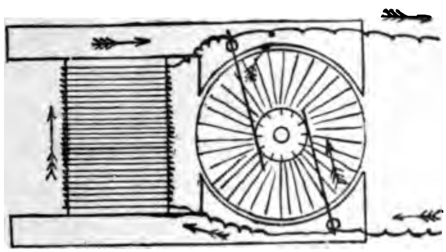

FIG. 15.—SHUNT-WOUND DYNAMO.

extent *self-regulating*—that is to say, capable of accommodating itself to the requirements of the outer circuit ; since, when a great resistance is placed in the outer circuit and there is a necessity for a greater E. M. F. to overcome this outer resistance, more current is supplied to the field-magnets, hence more magnetism is evoked, and a greater E. M. F. is set up in the armature. On the other hand, if the outer resistance is low, and little E. M. F. required to overcome it, less

current is forced through the comparatively high resistance of the shunt coils, the field-magnets becoming consequently but little magnetised, and a lower E. M. F. results. There is another peculiarity connected with the shunt-wound dynamo, that renders it eminently suitable to charging the *accumulator*, the consideration of which we defer until we have made acquaintance with this last-mentioned apparatus.

19. Partaking of the characteristics of both the *series-* and *shunt-wound* dynamos are those known as "*compound-wound*," or "*series and shunt*" machines. In these the field-magnets are wound first with a layer or more of coarse insulated wire, and this is connected in series with the outer circuit as in the ordinary series machines. Over this, or in some cases parallel to this, on a portion of the electro-magnets left bare for the purpose, are coiled a number of layers of fine wire which, as in the "shunt" machines, are connected directly to the brushes. The effect of this arrangement is to render the dynamo capable of adapting itself to very great and sudden changes in the resistance of the outer circuit, without influencing its electro-motive force, and thus rendering it almost perfectly self-regulating. The manner in which this double winding effects this purpose will be evident on examination of Fig. 16, in which *A* represents the armature,

B B the brushes, *C C* the series coils, *D D* the field-magnets, and *E E* the shunt coils. The current set up by the armature *A* if it meet with a large resistance in the outer circuit *O* will not be able to traverse

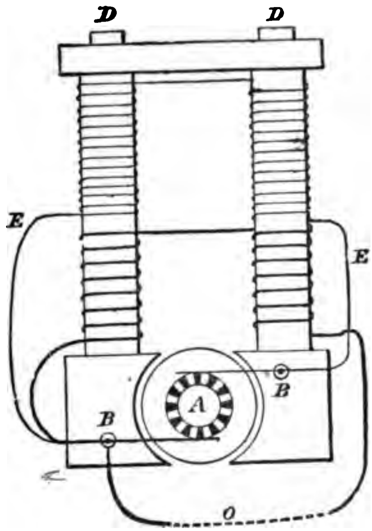

FIG. 16.—COMPOUND-WOUND DYNAMO.

that resistance and give a large current sufficient to excite the magnets and do the work in the outer circuit. But owing to the fact of the "shunt" coils *E E* being connected to the brushes *B B* if the resistance of these coils be not too great, sufficient current will

pass around their many convolutions to magnetise the field-magnets *D D* and enable them to set up a powerful current in the armature, irrespective of the current which may pass through the series coils. Again, if the outer resistance at *O* were so low that the shunt coils *E E* were to oppose a resistance comparatively so high as to prevent sufficient current passing round the field-magnets *D D* through their medium, then the series coils would come into play, and the field-magnets acquire their magnetism through these latter. So that, within very large limits, the compound-wound dynamo is capable of adapting itself to the variations in the resistance of the outer circuit—a circumstance which renders these machines eminently adapted to the lighting of incandescent lamps, where one or many lamps may be suddenly required or as suddenly shut off.

20. The factors on which the output of a dynamo depends are :—

1st. The intensity of the magnetic field.

2d. The length of wire on the armature which cuts the lines of force in this magnetic field.

3d. The resistance in the wire wound on the armature itself.

4th. The nature of the iron of which the field-magnets and armature are constructed.

5th. The amount of current wasted in setting up the magnetic field in the field-magnets themselves.

Now the intensity of the magnetic field depends itself on two causes: firstly, the softness and magnetic permeability of the iron constituting the field-magnet; and secondly, the amount of current (or what comes to the same thing, the number of ampère-turns)* required to magnetise them. The softness of the iron is of the greatest importance, since soft Swedish iron is capable of acquiring, under the influence of a given current, 40 per cent more magnetism than the same bulk of ordinary cast-iron. Since the intensity of current set up in a given magnetic field depends on the number of lines of magnetic force cut in a given time, it follows that we can get the same result either by increasing the size of the armature, which enables us to get on a greater length of wire, and in that way cut more lines, or else by driving the armature at a higher speed, by means of which a shorter length of wire may be caused to cut as large a number of lines. In practice, in good modern machines it is found that with an angular velocity † of 1250 feet per minute it is possible

* By ampère-turns is meant the number of turns of wire equivalent to a single turn carrying one ampère. See § 18.

† Angular velocity—the velocity with which a point on a circle travels when the circle is rotated. It is also called peripheral velocity.

cent of the energy put into them as motive power; in other words, it is possible to obtain from 95 to 97½ per cent of electrical energy from a dynamo absorbing 100 per cent of mechanical energy to drive it.

22. The following illustrations will give a good idea of the more modern types of dynamo machines, irrespective of the mode of winding; since any of these dynamos, with the exception of those specially noted above, can be wound either in series, in shunt, or as compound machines.

The first to claim our attention, as being the oldest and very well adapted for small experimental work, is the old Siemens H-girder armature dynamo, Fig. 17.

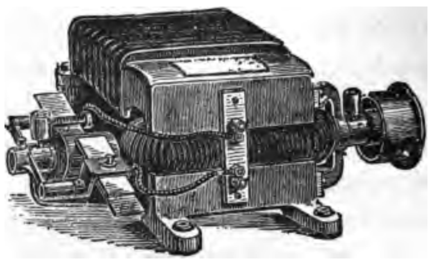

FIG. 17.—THE OLD SIEMENS H-GIRDER.

It may be mentioned here that this, owing to its two-section commutator, is not well adapted to accumulator-charging.

The second machine is the drum-armature dynamo,

ance of the dynamo and the amount of current required to energise the field magnets as low as possible.

21. It has been found that to produce a given electro-motive force and current a certain expenditure of power is indispensable, since electricity itself is but another form of motion, which requires power to produce it. It is also found that, whether we seek to produce 1 volt and a current of 1000 ampères or 1000 volts with a current of only 1 ampère, the power expended will be the same; so, for the convenience of calculation, the term *watt* has been introduced, to indicate the amount of electrical energy contained in 1 volt $\times$ 1 ampère. One horse-power of mechanical energy, which is equal to the work done per minute by 1 lb. falling through 33,000 feet, or by 33,000 lbs. falling through 1 foot, is equivalent to 746 watts. This means that if we could convert directly, without any loss through friction or any other imperfection, 1 horse-power of mechanical energy into electrical energy, we should obtain 746 watts. As we can subdivide the watts into ampères and volts at our discretion, so we could at will obtain either 746 ampères at 1 volt pressure or 1 ampère at 746 volts pressure, in exchange for our horse-power; or any two factors of volts and ampères which multiplied together produce 746. In practice the best modern dynamos waste in conversion from 2½ to 5 per

—next claims our attention. The forms given to the field-magnets are various, but the peculiarity of the Pacinotti armature lies in the manner of winding and in the presence of the projecting teeth. The Pacinotti armature is represented at Fig. 19, from which it will

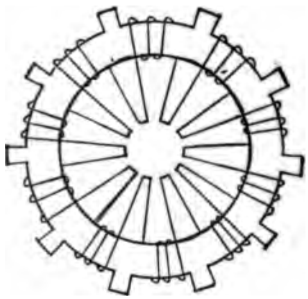

FIG. 19.—PACINOTTI ARMATURE.

be seen that a wide ring, either of cast-iron or, better, built up of a number of laminæ of soft sheet-iron with projecting teeth, is wound inside and out between each cog with layers of wire, and that the extremity of the wire which terminates the coils in the one section is joined to the starting extremity of the wire in the adjacent section, and so on all round the armature; the joined ends in each section being in turn connected to a commutator consisting of as many parts as there are sections in the armature. The original form of Pacinotti dynamo with vertical magnets and hori-

zontal horned pole-pieces is not at present used. The Pacinotti armatures are still largely used in such machines as the Gramme, Fig. 20, the Manchester, Fig. 21,

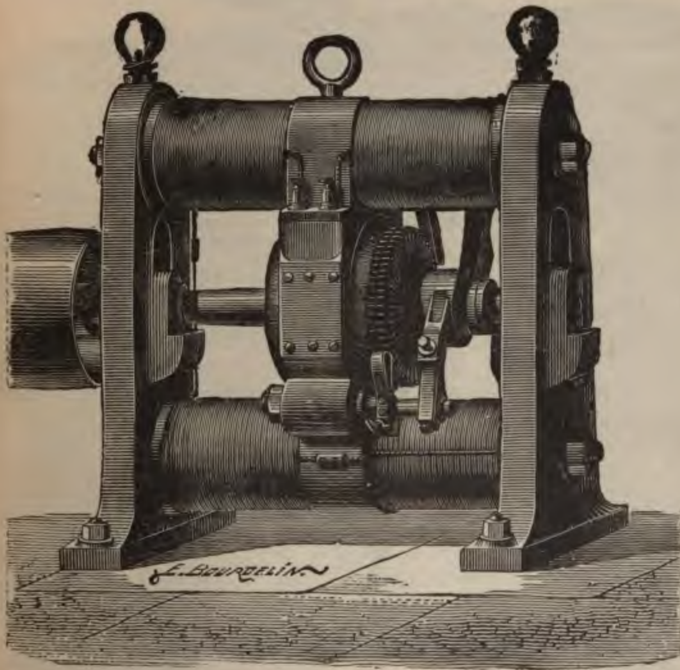

FIG. 20.—GRAMME DYNAMO.

the Kapp, Fig. 22, the Phœnix, Fig. 23, and similar types.

Closely allied to the Pacinotti armature is that in

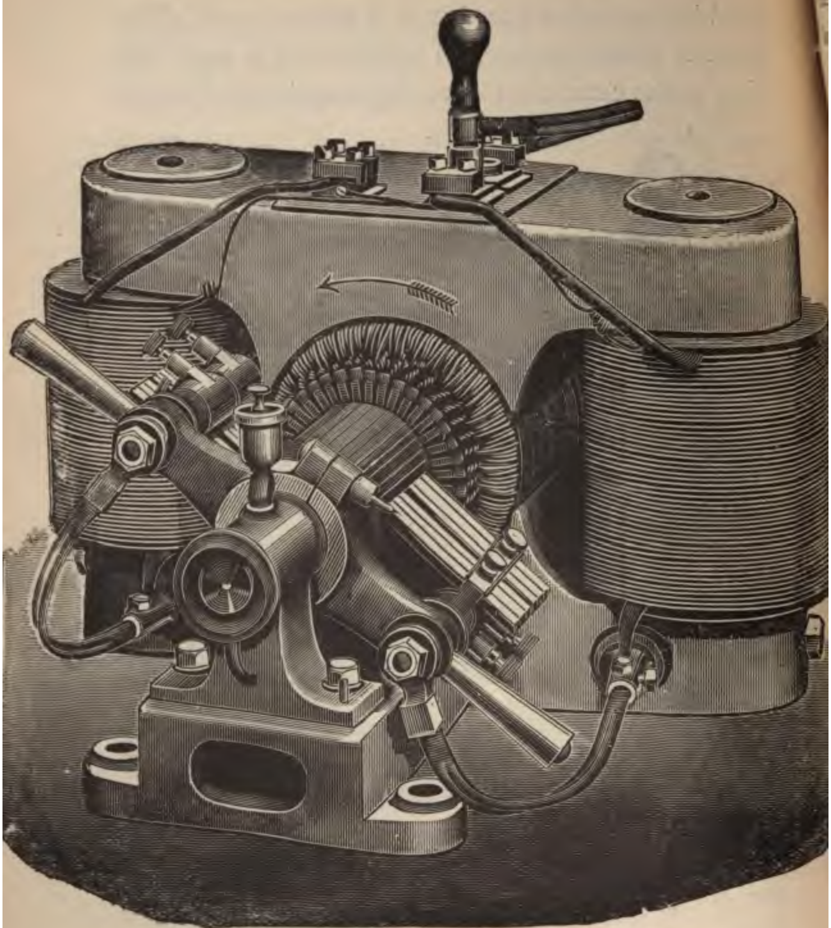

FIG. 21.—MANCHESTER DYNAMO.

the old form of Brush machine, Fig. 24; in which, however, the connections of the wires of the armature-

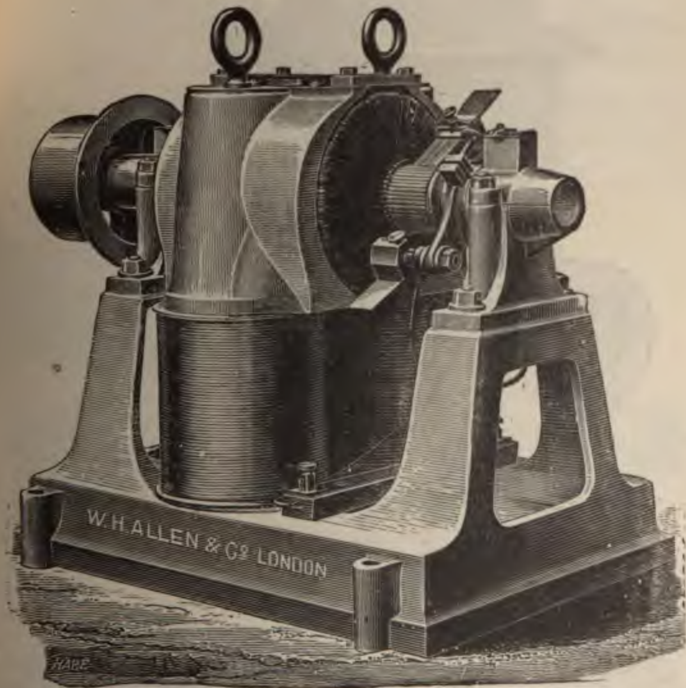

FIG. 22.—KAPP DYNAMO.

coils to the commutator, as well as the commutator itself, are different.

Another machine which from the peculiarity of the

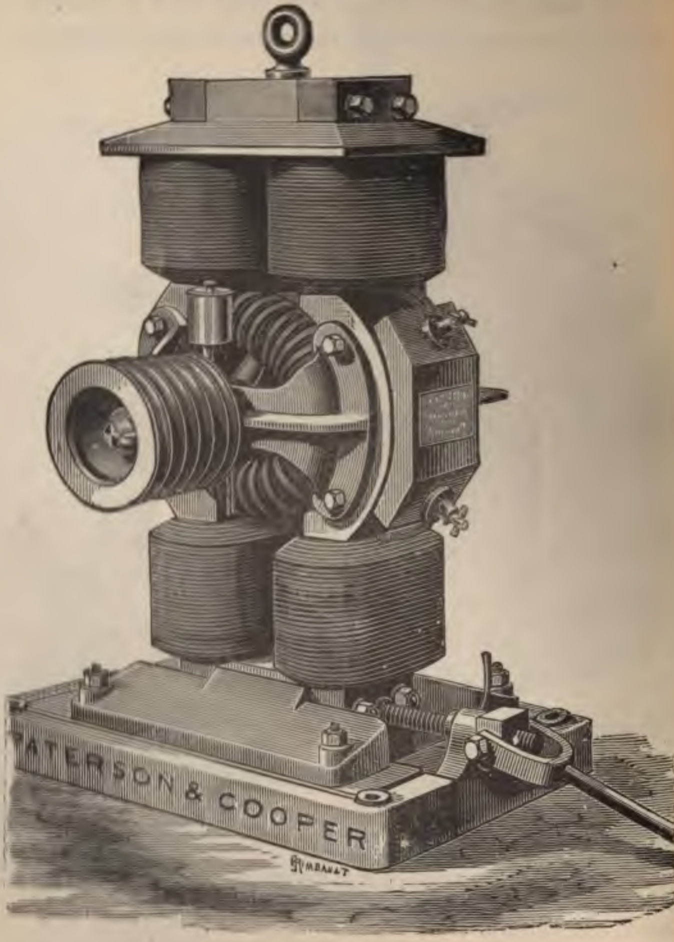

FIG. 23.—PHŒNIX DYNAMO.

shape of its armature is worthy of attention is the Thomson-Houston, Fig. 25. In this the armature takes the form of a sphere of iron overwound with three sections of wire lying at an angle of 120° with each other; the ends of which are joined to a three-part commutator of peculiar form. This armature runs in two hemispheres which form the pole-pieces of a cylindrical

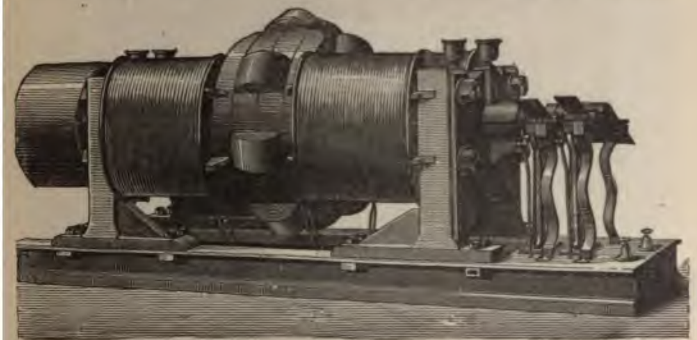

Fig. 24.—Brush Machine.

magnet. Owing to the sudden changes of potential * which take place in this machine there is a good deal of sparking at the brushes while it is at work; and a very quaint device has been adopted by the inventors in the shape of a nozzle to supply a blast of air to blow away the sparks and thus obviate this defect. This is effective in so far as getting rid of the sparks is con-

* Potential—electric level.

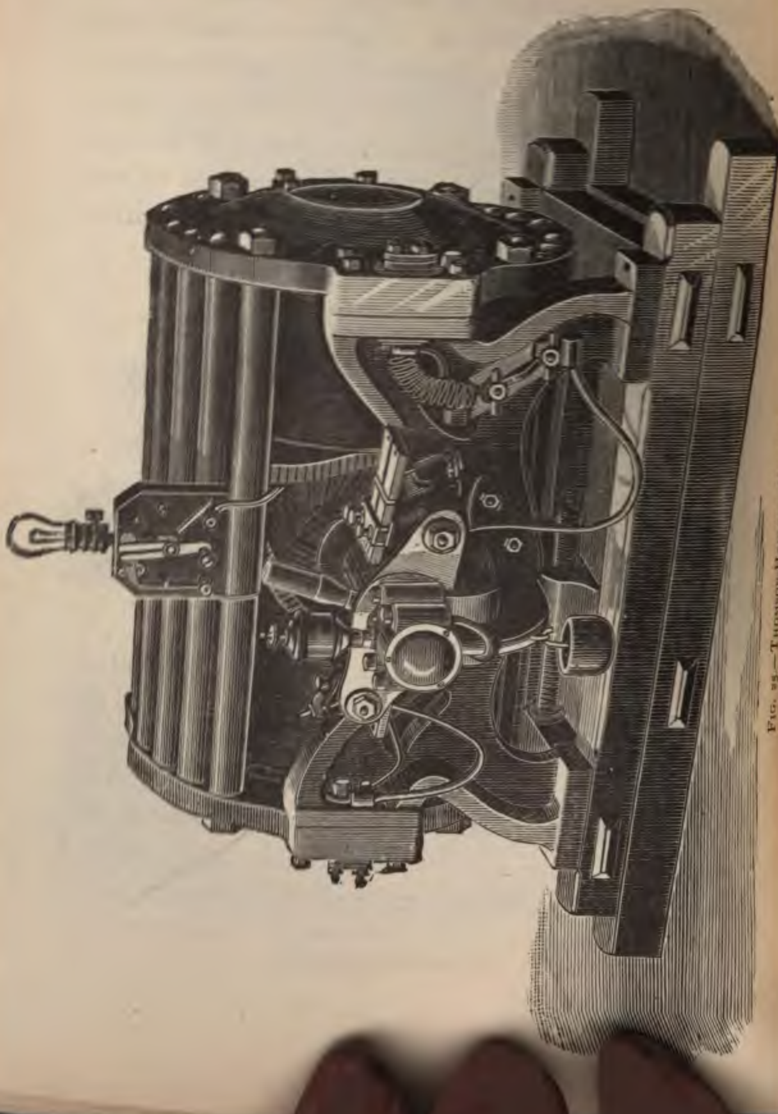

FIG. 25.—THOMSON-HOUSTON MACHINE.

cerned, but the waste of current of which these sparks are but the indication is not remedied in like proportion.

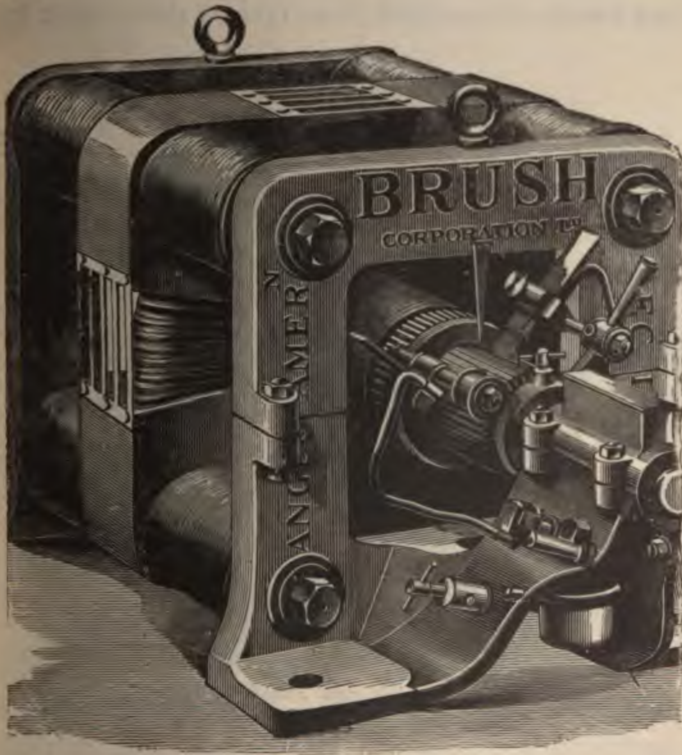

FIG. 26.—VICTORIA-BRUSH DYNAMO.

A very beautiful and effective form of dynamo is Mordey's modification of the Schuckert, known as the

Victoria-Brush dynamo. In this we have a ring-armature without teeth, running between six pole-pieces arranged on a hexagonal frame, with the commutator and brushes so arranged as to take off the current in

FIG. 27.—MORDEY ARMATURE.

one continuous direction by means of one pair of brushes only. This is shown in Fig. 26.

The last of the many existing modifications in the forms of dynamos which we shall illustrate is the

Mordey alternator, Figs. 27, 28. In this machine (which is intended to supply alternating currents only) the usual disposition in the parts of a dynamo is reversed. Here the armature (built up of a number of

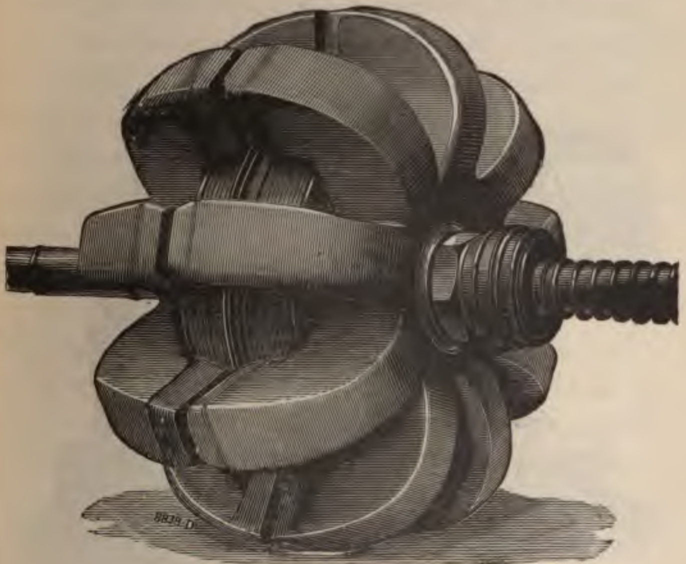

FIG. 28.—MORDEY FIELD-MAGNETS.

wedge-shaped cores, around which wire is coiled, connected up as shown at Fig. 27 and placed on the periphery of a circular frame) stands stationary between the claws of a peculiar spider-shaped electro-magnet, shown at Fig. 28. This magnet itself forms the mova-

ble portion of the machine, and is driven round at a high speed on its axis. The entire machine, with its armature and field-magnets enclosed in an outer protecting case, is illustrated at Fig. 29. This machine

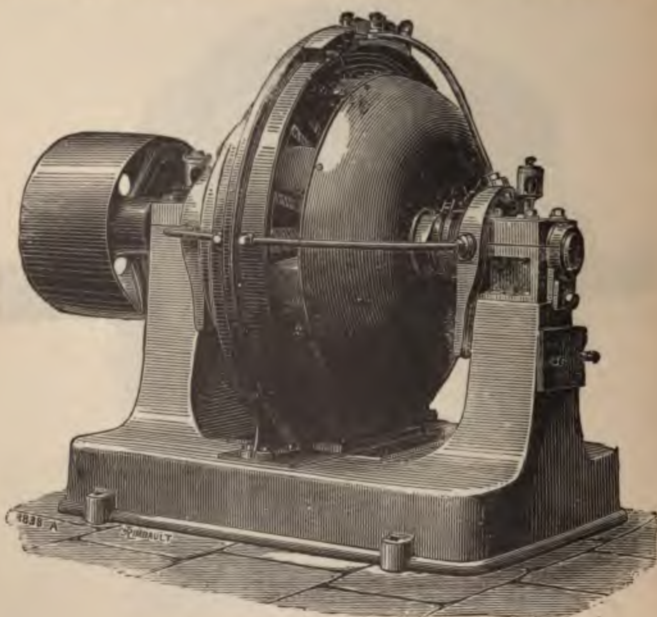

FIG. 29.—MORDEY MACHINE COMPLETE.

requires, in order to make it generate current, that it should itself be supplied with a small direct current, sufficient to magnetise the field-magnet, from a small separate dynamo (hence called an exciter) and gene-

lly, though not always, affixed to the main machine d driven from the same spindle: this, however, is ıt illustrated in our figure.

23. In choosing among these many forms of dyna-ɔs, the purchaser must ask himself the questions as what amount of current he will require, what resist-ce he will have in circuit, and for what special pur-se he requires the current. If lighting lamps known arc lamps (to be described farther on) be his inten-ın, the preference will lie with machines which are *ies*-wound. If, on the contrary, incandescent lamps in view, then *shunt*-wound or *compound*-wound namos will be indicated; the latter more especially ıere the number of lights to be kept going is likely be suddenly, greatly, or often varied. In cases where her classes of lights are not fed directly from the namo, but with the intervention of *accumulators*, the unt-wound dynamo alone is admissible, since under influence of the "back current" set up by these cumulators all other forms of dynamos are liable to ve their polarity reversed. In cases in which very all installations (such as four or five lights only) are uired, the Siemens H form with laminated arma-e will be found to give extremely good results. It also well adapted for all small experiments, which be better performed with small hand-dynamos of

this type than with any other. But the Siemens dynamo is not well adapted for large installations. Owing to the two-part commutator there is a very great and sudden change of potential when the slits of the commutator pass underneath the brushes. This gives rise to much sparking, which in its turn burns the brushes, roughens the commutator, and wastes power; and the heavier the current the machine has to supply the more painfully evident do these defects become. In calculating the output of the machine that will be necessary to do a given work we have to consider the resistance in the circuit and the amount of current required to do the given work. As an example which may be useful to those who desire to erect a small electric-lighting plant for themselves the following supposed case is given:—

24. It is desired to know what dynamo will be required to light directly (without intervention of accumulators) thirty lamps, each of 50 ohms resistance and each taking 1 ampère of current, so as to give 16 candle-power each. If the thirty lamps were connected one to the other in one continuous line, the total resistance of the combination would be $30 \times 50 = 1500$ ohms; and to get a current of 1 ampère through 1500 ohms resistance we should require the high electromotive force of 1500 volts; since, by Ohm's law,

$$\frac{E}{R} = \frac{1500 \text{ volts}}{1500 \text{ ohms}} = 1 \text{ ampère},$$

and this without taking into account the resistance of the conductors which lead from the dynamo to the lamps. It is true that were we to arrange the lamps in this fashion, only 1 ampère of current would be needed to supply *all the lamps;* so that the engine-power required to drive such a dynamo would be equal to 1500 volts × 1 ampère = 1500 watts; and since 746 watts are equal to 1 horse-power, the dynamo would require at least (1500÷746=) 2·02 horse-power to drive it.

The employment of a current at such a high pressure as 1500 volts is not advisable (owing to the difficulty of insulation and the danger of taking severe, nay, even fatal shocks from accidentally uncovered wires carrying such a current), except in certain particular cases which will be noticed farther on. But we are not bound to run the lamps *in series* with each other as described above and as pictured below: Fig. 29*a*.

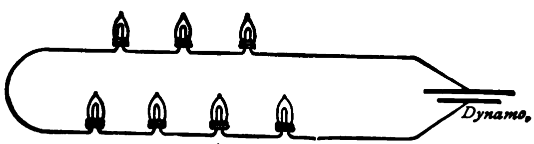

Fig. 29*a*.—Lamps in Series.

We can take advantage of the fact that the current will divide itself and flow along any conductors forming part of the circuit; and that the amount of current carried by each particular conductor will be inversely as the resistance of that conductor. Hence, by hanging the thirty lamps in *parallel with each other* across the two main conductors proceeding from the dynamo, we can light up all the lamps with a pressure not exceeding the 50 volts required to force the current through the resistance of 50 ohms; but in this case, as the resistance of the thirty lamps will be only $\frac{1}{30}$ that of a single lamp, since all thirty are arranged in parallel,* so that each carries its share of current, the total resistance of the lamps is only $\frac{50}{30}$ or 1·6 of an ohm; hence the total current flowing is 30 ampères—just what is required to light the thirty lamps. This we can also see by again applying Ohm's law.

Electro-motive force, 50 volts; resistance of thirty lamps (each of 50 ohms) arranged in parallel, $\frac{50}{30}$ or 1·6 of an ohm. Therefore :—

$$\frac{E}{R} = \frac{50 \text{ volts}}{1{\cdot}7 \text{ ohms}} = 30 \text{ ampères};$$

* When lamps or any other conductors are arranged in series, their resistance is increased in the same ratio as the number added. But when they are arranged in parallel, the resistance falls in proportion to the number placed in

of which each lamp takes 1 ampère, as required. The arrangement of lamps in parallel as required to fulfil these conditions is shown in Fig. 30.

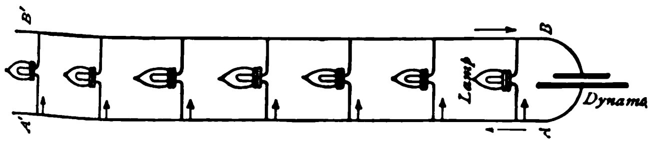

FIG. 30.—LAMPS IN PARALLEL.

25. It will be interesting to note, in this connection, that although we have varied the relative number of volts and ampères required to light the thirty lamps, yet, as the total number of watts remains the same, the horse-power required to drive the dynamo also remains the same. In this last case we have 30 ampères at 50 volts pressure or $30 \times 50 = 1500$ watts, and this, as we have seen, is equivalent to a little over 2 horse-power. As we must also take into consideration the resistance of the cables which lead from the dynamo to the lamps, technically known as "leads," it will be well to allow for a little more horse-power, so as to produce a little higher electro-motive force to overcome this additional resistance. So that, knowing the number and

parallel: in the same way as a given pipe 20 feet long would oppose double the resistance to the flow of water that a pipe 10 feet long would do; whereas if ten pipes each 10 feet long were arranged in parallel, the resistance would be only on one tenth that of a single pipe.

resistance of the lamps in circuit with the amount of current required to cause them to give the full amount of light, it is an easy matter to calculate the voltage and ampèrage that the dynamo should give in order to fulfil the requirements.

26. When we come to treat of the lamps themselves we shall notice that makers generally denote by numbers placed on the lamps the number of volts required to drive the requisite amount of current through these lamps to enable them to give the desired candle-power; and by reference to their lists (of which a condensation will be found in the sections devoted to lamps) the amount of current in ampères needed to produce the desired light with a particular make of lamp will be seen. In this place it will suffice to point out that a lamp marked 48^{v} 16^{cp} would indicate that the said lamp requires an E. M. F. of 48 volts to enable it to give 16 candle-power: and if on reference to the makers' list it were found that these 48^{v} 16^{cp} lamps take 1 ampère current, we should have all the data necessary to enable us to calculate the output of the dynamo required to light any number of such lamps.

27. In the choice of a dynamo the points which demand attention, besides those already mentioned referring to output, are the details of mechanical construction. In the first place, it is essential that

the bearings should be long and strong, so as to resist the strain of the belt without vibration; that the bearings should be well lubricated; that the standards should be strong; that there should be plenty of iron in the field-magnets; that the wire on the armature should be of such a gauge as to be able to carry the entire maximum current producible without injurious heating. To enable the reader to judge for himself of the diameter of the wires required to carry currents safely, the following table is appended. It must be borne in mind in using this table that on armatures of the *drum* and the *ring* types, since the current traverses the coils in the upper half and the lower half

TABLE OF SAFE CARRYING CAPACITY OF WIRES.

B. W. G.*	Diameter in Inches.	Current in Ampères safely carried.	Resistance of Wire per 100 Yards.
No. 3	0·25 inch	100 ampères	0·049 ohm
" 5	0·220 "	75 "	0·063 "
" 7	0·180 "	50 "	0·100 "
" 8	0·165 "	40 "	0·120 "
" 9½	0·141 "	30 "	0·165 "
" 10	0·134 "	25 "	0·182 "
" 11	0·120 "	20 "	0·227 "
" 13	0·095 "	15 "	0·362 "
" 14	0·083 "	10 "	0·474 "
" 15	0·072 "	7½ "	0·630 "
" 16	0·065 "	6 "	0·777 "
" 17	0·058 "	5 "	0·980 "
" 18	0·049 "	3 "	1·360 "
" 19	0·042 "	2 "	1·850 "
" 22	0·028 "	1 "	4·164 "

* B. W. G. = Birmingham wire gauge.

Fig. 49, in which two binding-screws are screwed as terminals onto a block of wood, the one binding-screw having below it a fixed block of metal, the other a sliding lever-arm, also of metal. This movable arm travels in the segment of a circle, between the fixed metal block and a pin which limits its play. When the movable lever is on the metal block, as there is perfect contact between the two terminals, the current

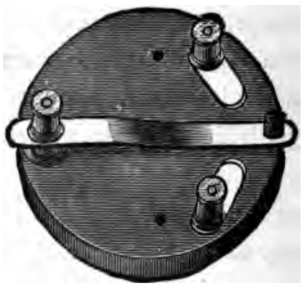

FIG. 49.—SIMPLE SWITCH.

flows without let or hindrance; but when the lever-arm is placed against the pin, as there is no connection between the two terminals no current flows. Small switches of this kind are useful between the mains and separate lamps; but where a large current has to be carried, heavier switches of a more complex character are requisite. A very good form of main switch is shown in Fig. 50, in which two metallic rings built up

CHAPTER III

28. HAVING now acquired some knowledge as to the means whereby current electricity can be obtained for feeding lamps, etc., we can turn our attention to the lamps themselves. Electric lamps fall naturally into three great classes, namely:

I. Those in which the light is produced between two pencils of carbon separated by a small interval which, in action, is bridged over by minute particles of carbon or other matter heated to whiteness by the passage of the current, which thus "bridges" over or "forms an arc" across the gap. These are known as "*arc lamps.*"

II. Those in which a wire of some infusible metal or a filament of some refractory conductor, such as *carbon* in one of its forms, or *boron*,* or *silicon*,* is enclosed in a glass vessel from which all air has been exhausted, and which wire or filament, by the resist-

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* **Two elements, much resembling carbon in general appearance.**

ance which it opposes to the passage of the current, becomes heated to incandescence when a current is caused to flow through it; and which are therefore called incandescence or incandescent lamps.

III. Those which partake of the characteristics of both classes, and in which the points of the carbons are either in actual contact or very nearly so, and in which therefore no true arc is formed, but the light is evolved in consequence of the intense heating of the points in contact, and in which no attempt is made to exhaust the surrounding air, as in the true incandescent lamp described above.

Of the first class we figure a simple typical form which will enable the reader to understand the construction of the more complicated forms. This lamp is known as *Archereau's* (Fig. 31). It consists of a bobbin *A*, wound with coarse copper wire, covered with cotton for insulation, having within it a movable soft iron core *B*, which can slide up and down inside the bobbin. The motion of this core is controlled in two modes at once. In the first place, it is impelled *upwards* by means of a cord passing over a pulley, to which is attached a counterpoise *C*. In the second place, the passage of a current round the wire coils of the bobbin *A* tends to draw the iron core downwards, or suck it into the tube, with a force that

would be possible by turning the handle more or less, so as to cause it to rest on one or the other of these separate sections, to send the current along any particular circuit connected to *that* binding-screw which happened to be in contact with the particular plate on which the strips were temporarily resting.

This leads us to the consideration of *two-way* and *multiple-way* switches, one of which is shown in Fig. 52.

FIG. 52.—MULTIPLE-WAY SWITCH.

The illustration almost explains itself. The central handle carries the spring contacts, which pass over separate metal plates connected with different circuits. The ingenuity of inventors has displayed itself in many

ways to produce switches which shall ensure good contacts and obviate sparking as much as possible. In some cases attempts have been made to introduce, gradually, varying resistances, so as to reduce the current from its full amount to a minimum, while turning the handle from *on* to *off*, so as to render the switch absolutely sparkless; in others, springs are adapted to the handle so that the switch cannot be left accidentally half on or half off (this is necessary to avoid the accidental formation of an arc in the switch itself); in other cases, safety *fuses* consisting of given lengths of tin wire which melts and thus breaks circuit automatically, if too heavy a current is passing, are included in the circuit of the switch. But the instruments described above will give the intelligent reader a sufficient idea of the mode in which all switches work. There is another form of connector known as a "plug switch," which, as the name indicates, completes circuit by the insertion of a metal plug in a conical hole between two metal plates.

All these switches, but more especially those intended to carry heavy currents, should be carefully insulated. The bases of the smaller ones (those not carrying more than from 1 to 5 ampères) may be of well-seasoned mahogany boiled in melted paraffin-wax, or of ebonite; but those carrying the heavier

currents on the main circuit, say from 5 to 50 ampères and upwards, should be mounted on slate bases, to prevent any accidental firing through sparking or otherwise. According to the Board of Trade regulations, "switches," "commutators," etc., must be mounted on incombustible bases, and when the handle is moved or turned to and from the positions of "on" and "off" it should be impossible for it to remain in any intermediate position, or to permit of a permanent arc or of heating; also that the handle of every switch must be completely insulated from the circuit.

54. We have noticed in speaking of lamps that incandescence lamps have either platinum loops left at one extremity for connection to the conductors, or else collars (either of *vitrite*, which is a kind of black glass, or else of brass) with two brass plates at their upper surface by which connection can be made. Neither of these systems alone is suitable for attachment to the leads without the intermediation of some kind of holder, and the holders themselves (except in a very primitive form of installation) are not sufficiently elegant or convenient for general use. For this reason brackets or pendants must also be employed. These do not differ very greatly in outward appearance from those employed by gas-fitters, the chief difference being, of course, that the hollow part of the stem

which in ordinary gas-brackets permits the flow of gas, serves in the electric bracket to carry the wires which convey the current to the lamps. We illustrate in Fig. 53 the pattern of holder mostly in use

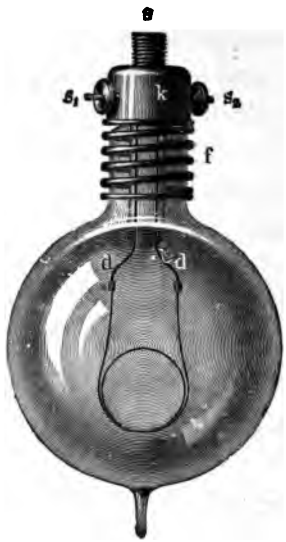

FIG. 53.—EDISON-SWAN SPRING HOLDER.

for bottom-loop lamps. *A* represents the Edison-Swan spiral-spring holder, in which two terminals on the outside of a circular wooden base communicate with two central hooks which enter into and serve to hold the loops of the bottom-loop lamps. In order to secure firm contact and yet to allow easy detachment

heated to whiteness in closed vessels. By these means carbon rods are produced which are fairly good in texture; this latter point being of considerable importance in order to ensure steadiness in the light produced.

30. The effect of the bobbin-coil shown at *A* in Fig. 31 in pulling down the iron core depends on the fact that a current of electricity produces magnetic properties at right angles to the direction of its flow; and by increasing the number of turns which a wire carrying the current makes, we are enabled to increase this magnetic effect; so that with a suitably wound bobbin or "solenoid," as such a hollow bobbin is called, we can produce any desired amount of pull with a given current by increasing or diminishing the resistance in circuit.

31. We may now direct our attention to some of the more modern forms of arc lamps in which the position of the arc is kept invariable, notwithstanding the unequal consumption of the carbons forming the arc. On examination, by means of a smoked glass, of the carbon points while the arc is formed, it will be noticed that the carbon from which the current starts, called the "positive" carbon and usually placed *uppermost*, becomes *hollowed out;* while the lower carbon, which receives the current and which is known as the

"negative" carbon, is not consumed to anything like the same extent, and becomes coated at a little distance from its extremity with a number of little nodules or protuberances, consisting chiefly of impurities in the carbon. It would appear that the particles of the positive carbon in a very fine state of division are actually disintegrated and carried forward by the issuing current to the lower carbon, to which some adhere. It must not be supposed that the light is produced by any real combustion of the carbon, as we see in the case of a lighted candle, or of coals in a fire; because comparatively little heat is diffused, and little or no oxygen absorbed from the atmosphere. Doubtless some of the carbon is oxidised; but the light itself is due to the rapid molecular motion set up in the particles of carbon disintegrated and carried along by the arc. The rate at which the upper or "positive" carbon is thus consumed or disintegrated is nearly double that of the lower or "negative" carbon; and many ingenious appliances have been devised to keep the rate of feed of the two carbons so adjusted that the point where the arc is produced shall remain stationary, notwithstanding this unequal consumption of the carbons.

32. One of the first forms of lamp which satisfactorily fulfilled the requirement of keeping the arc at

one fixed point is the *Serrin* lamp which Fig. 32 illustrates. Here we have an electro-magnet at *e* which, when the current is passing, attracts an armature *a'*: the latter then pulls down the lower carbon

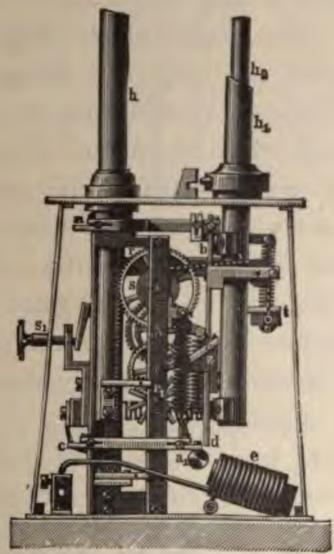

FIG. 32.—SERRIN LAMP.

h', thus causing it to separate from the upper carbon and "strike" the arc. The upper carbon is held by a holder in a rectangular arm similar to that of the Archereau lamp,—with this difference, that, instead of being attached to a plain rigid pillar, this arm is

connected to a heavy brass rod sliding in a tube *h*. At the lower extremity of this rod is a rack the teeth of which engage with a train of wheels governed by a fly, which train is so adjusted as to drive upwards the lower carbon at half the rate at which the upper carbon falls. The weight of the rack-bar itself is sufficient to start the train and bring the carbons together: and this it would do were it not controlled by the armature, which when pulled by the electro-magnet, under the influence of the current, throws forward a detent which stops the motion of the fly-wheel, and thus prevents any farther motion until, by the increasing distance of the carbons, the current is so far weakened as to release the armature and detent, which therefore frees the fly-wheel and allows the carbons to approach.

33. The *Gaiffe* lamp is also a "focussing" lamp,* and may be described as a cross between the Serrin and the Archereau. It consists essentially in a vertical coil of thick wire (Fig. 33), in which works a soft iron plunger, which is sucked into it when the current passes. This bar is toothed along a portion of its length, and actuates a wheel of 25 teeth, the axis of which carries another wheel of 50 teeth, insulated

* Focussing lamps—those in which the focus or arc remains in an invariable position.

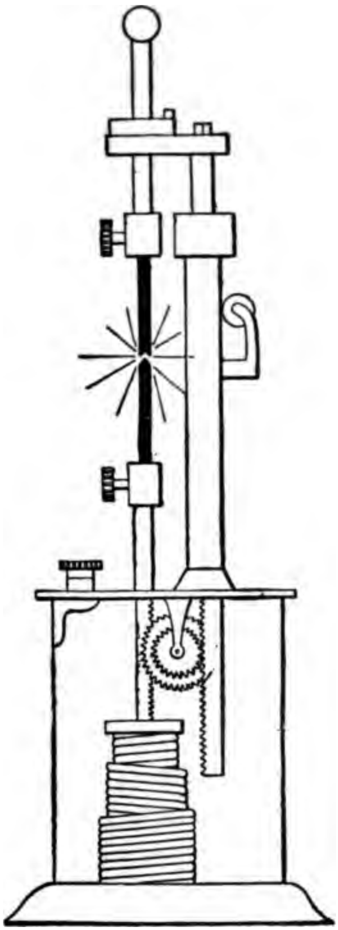

FIG. 33.—GAIFFE LAMP.

registers the amount of attraction, and consequently the strength of the current, by means of appropriate devices connecting the core to an index which denotes on a dial the extent of attraction and the value of the current. Instruments of the former class are generally

FIG. 59.—JOEL PATERSON AMMETER.

very delicate in their registrations, and are suitable for measuring currents produced by batteries. But they are liable to three defects. Firstly, masses of iron or magnets or dynamos in their vicinity, by affecting the magnetic needle, falsify their readings and vitiate the results. Secondly, since the deflections do not increase

affixed to the main standard *K* of the lamp. This main standard carries at its upper extremity a bent arm standing over the lower carbon, terminating in a tube in which the upper carbon rod can easily slide.

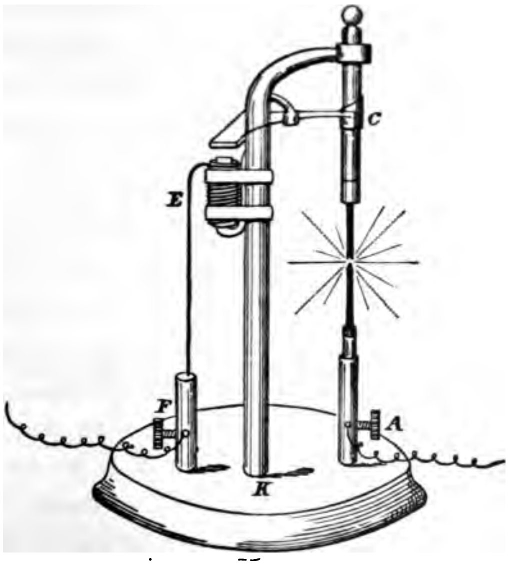

FIG. 34.—BROWNING LAMP.

Pivoted on the main standard, at a little distance from the electro-magnet, is an armature *D*, a prolongation of which carries a "clutch"-piece *C* that, when the armature *D* is attracted by the electro-magnet *E*

can be forced through the instrument, we must construct this latter of so high a resistance that the internal resistance of the source of electricity, be it battery or dynamo, shall be so small when compared to that of the voltmeter itself, that its influence may be practically neglected.

To elucidate this, let us suppose that we constructed a voltmeter having practically *no resistance*, and that we tested successively two Daniell cells, one having an internal resistance of 5 ohms and the other of only 1 ohm; it will be evident from Ohm's law that, although the E. M. F. of these two cells would be exactly the same, yet, since the resistance of the smaller cell is five times greater than that of the larger, the latter would send five times the amount of current round the coils of the said voltmeter and consequently would give an indication of five times the value. This of course would be a false reading, since the voltage would be the same in both cases. But suppose that the voltmeter were wound with coils having a resistance of 250 ohms: it is quite evident that the difference in the total resistance when using the cell having 1 ohm resistance compared with the one having 5 ohms resistance will amount to only 4 parts in 255, or rather less than 2 per cent. Consequently a voltmeter wound to such a resistance can be depended

upon for giving true readings with such a variation in the internal resistance of the generator as 1 to 5 ohms, and greater accuracy if, as is the case with most dynamos, the internal resistance be smaller.

Figs. 61 and 62 illustrate two forms of voltmeter.

FIG. 61.—VOLTMETER (WALSALL).

The voltmeter, owing to its great internal resistance, cannot be placed in direct circuit with the battery or dynamo and the lamps, etc., since it would practically cut down the current to nothing; it is generally connected in shunt with a dynamo, etc., and corrections made for the resistance of the other parts of the circuit; or if it is desired to take the voltage either of

FIG. 62.—VOLTMETER (CARDEW'S).

a battery or of a dynamo by direct reading, the voltmeter is connected in the main circuit, and the other portion is disconnected or switched off.

The voltmeter is extremely useful for obtaining immediate information as to the efficiency in E. M. F. of the battery, accumulator, or dynamo in use, and the ammeter is no less useful in indicating the current. It may happen that a battery, etc., may denote by the voltmeter that it is giving its proper E. M. F., which on testing with the ammeter denotes a great deficiency in current, which may be due either to imperfect connection, to the corrosion at the points of contact, or to leakage along the line.

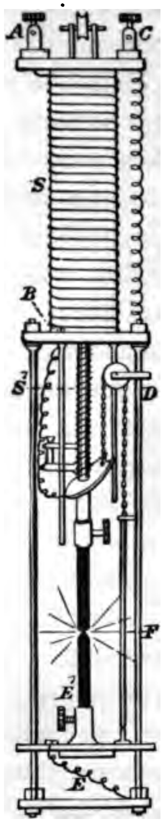

FIG. 36.—BEAUMONT LAMP.

about the same length, but only ⅜″ in di
wound with No. 36 German-silver wire; this f
shunt or branch circuit to the main current

through the solenoid *S*, and this second solenoid, *S'*, which is attached by means of an insulated hook to the chain and pulley. In action the current enters the binding-screw or terminal *C*, descends the iron guide-bar, and enters through the flexible wire *E* to the lower carbon *E'*, thence to the upper carbon, thence through the flexible wire attached to *B*, round the coils of the main solenoid to *A*; a portion of the current being deviated or shunted off through the fine wire of the smaller solenoid, which, being wound in the opposite direction, acts antagonistically to the pull of the main solenoid which tends to separate the carbons, and causes them to come together when the length of the arc has increased to such an extent through the consumption of the carbons as to allow the current to pass through the shunt-coils. When this happens, since the resistance of the main circuit becomes again less than that of the shunt, the larger solenoid, *S*, reasserts its power and the carbons are held immovable by the balanced action of the solenoids *S* and *S'*.

37. It will not be necessary in a work like this to enter more deeply into the description of other forms of arc lamp. The intelligent reader will have understood that the controlling arrangements are either clockwork, or electro-magnetic, or solenoid arrange-

ments for maintaining the carbons at a proper distance from one another. There is one point, however, connected with all arc lamps which it is of importance to bear in mind, as it has great influence on the production of a good arc light. This fact is, that when a current is sent through an arc lamp so as to produce an arc, a back or counter electro-motive force is set up in the arc itself having a pressure of nearly 39 volts. There is nothing new in this idea, for it is simply another demonstration of the well-known law that every action brought about by any force produces an equivalent reaction. The practical bearing of this fact upon the working of arc lamps is that it is impossible to produce a satisfactory arc light with an E. M. F. of less than 39 volts; and since the arc itself and the wires in the lamp present some resistance, it is usual to supply an E. M. F. of between 44 and 50 volts for each lamp. The experiments which led to the discovery of the counter electro-motive force in the arc were made by Edlund some twenty years ago. It has also been found that the actual resistance of the air-space when the arc is formed between the two carbons at a distance of about $\frac{1}{8}$ of an inch apart (which is the normal position for electric lighting) varies between $\frac{1}{8}$ and $\frac{1}{2}$ of an ohm. It appears, however, that the resistance of the arc does not increase

proportionately with the distance between the carbons; and as a matter of fact the resistance of an arc $\frac{1}{8}$ of an inch long is nothing like double that of an arc $\frac{1}{16}$ of an inch long. This may be partly due to the fact that with the larger current required to produce the longer arc, proportionately more of the carbon rods enter into action, so that as the section * is increased the resistance decreases in like proportion.

38. There is one modification of the arc lamp which differs so greatly from those above described that, although the light produced is a true arc, it has been thought advisable to devote a separate section to its consideration; this is known as the *Jablochkoff* candle. In this two carbon rods are laid side by side, separated by a small interval of about $\frac{1}{8}$ of an inch by means of a strip of plaster of Paris or pipe-clay: this arrangement is shown in Fig. 37. Across the top of the two carbons a weak connection is made by a line of powdered carbon made into a paste with gum. One carbon is attached to one terminal and the other to the other terminal of an alternating † dynamo. When the current passes (which must be *alternating*, otherwise the carbons will consume unequally and the light

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* All conductors increase in conductivity with the increase of section.

† A dynamo which gives a rapid succession of currents alternately in one direction and the other.

go out), the line of powdered carbon which bridges the gap between the two carbons conducts the current, but in so doing is immediately consumed, so that the true arc is formed. (The arc is not formed unless the carbons are in some way brought into contact and

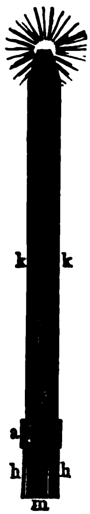

FIG. 37.—JABLOCHKOFF CANDLE.

then separated.) Under the influence of the enormous heat of the arc, the plaster of Paris or kaolin is melted, in proportion to the consumption of the carbons, so that the arc is maintained always of the same length.

39. We may now pass to the study of the incandes-

cent system of lighting. The principle on which incandescence lamps are constructed is based upon the fact that when a current of electricity flows along any conductor, that conductor becomes heated in proportion to the amount of current it has to carry, and to the resistance which it presents to the passage of that current. When the heat thus produced has reached a certain point, the body carrying the current becomes red hot; and if the amount of current be increased so that the temperature is further exalted, the conductor finally glows at a white heat or "incandesces." This state of incandescence must not be confounded with combustion: there is no true burning; that is to say, there is no combination of the body with the oxygen of the atmosphere. Of course, if a body which is capable of burning, i.e., of combining with the oxygen of the atmosphere, be exposed to the action of the air while thus intensely heated, it will ignite and burn away; but if the experiment be performed in a closed glass vessel from which all air has been exhausted by means of an air-pump, incandescence can be kept up without combustion taking place. The earlier experimenters in this direction employed metallic wires to carry the current, and the first practical lamp was that of *Edison*, in which a fine platinum wire, or a wire made of an alloy of platinum

and iridium, forming a loop between two terminals and enclosed in an exhausted glass bulb, acted as the conductor for the current. The difference between the temperature required to *incandesce* and that needed to *melt* platinum wire is so slight that in practice it was found very difficult to get a good light by this means without risking the melting of the platinum. As a consequence of this defect, Edison in the United States and Swan in England directed their attention to the construction of a conductor which, while not opposing too much resistance to the passage of the current, should have a sufficiently wide difference between its incandescing and its melting points to admit of a sufficiently strong current being sent through it without melting it or breaking it up. The result of their experiments led them to the construction of very fine filaments of *carbon*, in that modification known to chemists as *graphitoidal.* Graphitoidal carbon is produced by the expulsion of the gases contained in vegetable matter when subjected to great heat under pressure. Strips of paper, cotton, thin strips of bamboo, and other similar substances, when thus carbonised, have been used by different experimenters for the production of the conductors of filaments of these electric incandescent lamps. The form which seems to give the best result is obtained by dissolving pure

cellulose (or cotton-wool) in chloride of zinc, so as to form a thick glutinous paste very similar to thick glue. This is forced by pressure through a hole of the requisite diameter to produce a filament of the thickness required (which may vary from $\frac{1}{60}$ to $\frac{1}{36}$ of an inch, according to the conducting power which it is desired to give to the filament). These filaments are allowed to drop into alcohol, which hardens them, then bent into shape, such as a loop or double loop, and then carbonised by being exposed to a very high temperature, having been previously packed with finely powdered charcoal in an iron box. The filaments having been thus prepared, each extremity is attached, by means of a paste formed of finely powdered graphite mixed with a little gum arabic, to two platinum terminals inserted into a piece of glass. This piece of glass is then fused into one extremity of a pear-shaped glass bulb, the opposite end of which is left open to enable the contained air to be exhausted. To effect this the open end of the bulb is placed in connection with a Sprengel or similar high-vacuum air-pump, and when the air has been sufficiently exhausted from the bulb to ensure that the filament shall incandesce without burning, the small open end of the bulb is sealed by melting the glass in a hot flame, and the lamp is complete. Figs. 38, 39, 40, and 41 show the usual forms

given to incandescence lamps. Fig. 38 is the ordinar bottom-loop lamp, which shows the carbon filament, th points of attachment to the platinum, and the platinur

FIG. 38.—BOTTOM-LOOP LAMP.

FIG. 39.—BRASS-COLLAR LAMP.

FIG. 40.—FAIRY LAMP.

FIG. 41.—PENCIL-MICRO LAMP.

wires, the outer curls of which form the connectio of the lamp to the wires coming from the battery dynamo. The figure also shows the glass globe, ar

the sealed aperture from which the air was extracted. Fig. 39 shows the modification adopted to prevent these loops or curls being easily broken. This consists in fitting a brass collar, with two studs at diametrically opposite points of its circumference, to the bottom of the glass bulb, and soldering two brass segments to the extremities of the platinum wires which protrude from the glass globe, the spaces between the outer brass collar and the two segments, as also between the two segments themselves, being filled in with a paste of plaster of Paris which sets quite hard. Fig. 40 represents the "fairy" lamp, used for electrical jewellery and for similar minute illumination. Fig. 41 shows the so-called pencil-micro lamp, which is used by microscopists to illuminate objects on the stage of the microscope, and by medical men to examine the mouth, the ear, the throat, the nose, and even the interior of the stomach of some of their patients.

40. It is a property of all bodies to expand by heat, and glass is no exception to this rule; consequently when the current flows in an incandescence lamp as above constructed, the glass expands and the platinum wire which carries the current to the carbon filament expands likewise. It is a fortunate circumstance, and one which has conduced greatly to the perfecting of the modern incandescence lamp, that the rates of

that amount of power, minus the loss of conv
provided that the section of the wire be of su
size to carry the current supplied without h

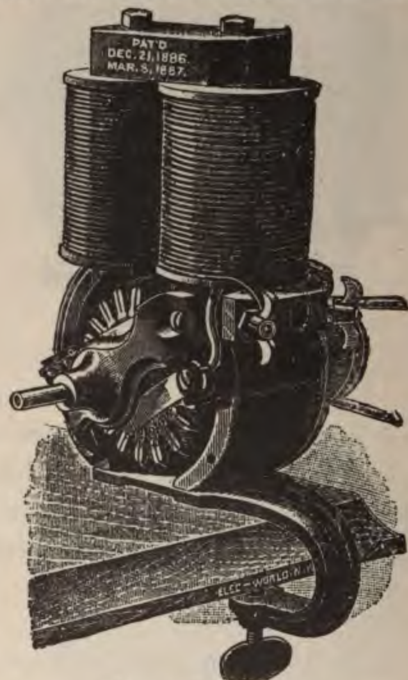

FIG. 73.—C. & C. MOTOR.

and provided also that the mass of iron in the
be of sufficient size not to become fully sat
with magnetism under the influence of the c
supplied. When the magnetic saturation-po

giving 16 candle-power will take about 1·18 ampères, since the watts required are still 56 to give the 16 candle-power, while, the voltage being low—viz., only 48—the number of ampères will be correspondingly greater.

41. In putting this knowledge to practical use, it must be borne in mind that the makers' mark of voltage refers only to the voltage required to drive the necessary amount of current through the lamps to produce the desired light, as supplied by a *dynamo;* in which the internal resistance is so low as to be practically negligible. But it must not be supposed that *any* source of electricity giving the number of volts marked on the lamp would necessarily supply the lamp with the necessary amount of current; since if the internal resistance of the supply of electricity (say a battery) were high, the necessary amount of current would not flow, and the lamp consequently would not glow. Makers of dynamos generally follow a rule by means of which the resistance of the dynamo is kept at $\frac{1}{20}$, or less, of that of the lamp or lamps which they are intended to run: so that a dynamo sold as fit to light the so-called 50-volt lamps would have an internal resistance so low and an electro-motive force so high as to enable it not only to overcome the resistance of the lamps, but that of its own armature

soon be out of the striking distance. But there is another and very important application of the alternate current, and that is the capability which it presents of being supplied at one point at a very high pressure, though small in quantity, and being converted at another point into a current of large quantity at a low pressure.

64. This is effected by means of a *transformer*, which consists essentially in an iron core wrapped round with two distinct coils of insulated wire, one fine and the other coarse. When an alternating current of high tension flows through the fine wire coils of such a transformer, it, without itself passing through the coarse wire coils, sets up a current (also alternate) in these coarse wire coils which bears the same relation to the original current with regard to quantity that the section of the wire in the coarse coils bears to the section of the wire in the fine coils. For example, supposing we have an alternating current of 1 ampère delivered at a pressure of 2000 volts, and we cause this to circulate through the fine wire of a transformer, the ratio of the resistance and coilings of the coarse wire to those of the fine wire being as 1 to 2000, we should get from the coarse wires an alternating current of 2000 ampères at a pressure of 1 volt only. The reader may feel curious to know what advantage

resistance of the lamp and that of the cells themselves. Since the E. M. F. of the 29 cells is 58 volts, the internal resistance being 2·32, that of the lamp 48 ohms, the equation now becomes $\frac{58}{50 \cdot 32} = 1 \cdot 1$ ampères, nearly.

Supposing that it were desired to instal such a lamp in a dark cupboard for momentary uses only (extending altogether over a long period), it might be deemed advisable to use Leclanché cells; but then, owing to their great internal resistance, a very large number would be required, arranged in several sets in parallel (to overcome this resistance), these being afterwards joined in series to give the requisite electro-motive force. This will be evident on examination of the table, from which it is apparent that as the internal resistance varies from 1·13 to 1·15 ohms, the electro-motive force being always 1·6 volts, a very large number of cells would have to be joined in series in order that, when coupled up to such a lamp of 48 ohms resistance, they could force 1·1 ampères through the combined resistance of cells and lamp. This will be rendered clear by an examination of the following example.

Let the lamp have a resistance of 48 ohms; let it be connected to 150 cells, each giving 1·6 volts and each having a resistance of 1·15 ohms. We get

currents over large areas in varying quantities and at different pressures, can do this economically and satisfactorily by means of alternate-current dynamos connected to comparatively thin but well-insulated conductors leading to transformers of given capacity at or near the place where the current will be utilised. Figure 74 is an illustration of a good type of transformer.

THE WOODHOUSE-RAWSON COMPANY LAMPS.

Candle-power.	Volts.	Candle-power.	Volts.
1- 3	4- 10	16-25	125-140
4- 6	10- 60	16-25	145-160
8-16	40-115	16-25	165-180
16-20	50-120	16-25	185-210
25-32	60-120	100	80-120
40-50	90-120		

These lamps generally take about 3 watts per candle-power, at which the average life is 1000 hours; but the company also supplies lamps that take only 2·75 watts per candle-power. These, of course, have not so long a life.

THE BERNSTEIN LAMPS.*

66 c. p.	45 volts.	4·5 ampères.
33 "	45 "	4·5 "
20 "	7 "	10·0 "

42. There is one point in connection with these incandescence lamps having carbon filaments which is of interest. When a current passes through a *metallic* conductor, such as a piece of wire, the resistance of the conductor is *increased* in proportion as the temperature rises; but in the case of the carbon filament of an incandescence lamp, the resistance *falls* with the increase of temperature. In other words, the "hot"

* These lamps are specially made for running in series; their resistance being low, they take a large current. Other sizes are made, but data as to exact voltage and ampèrage required are not at hand.

Dimensions of Room, in Yards.			Number of 10-candle-power Lamps.	Height of Lamps (in Yards) above Floor.
Length.	Width.	Height.		
5·0	5·0	4·0	2 to 3	2·2 to 2·4
6·0	6·0	4·8	5 " 6	2·4 " 2·6
8·2	8·2	5·8	9 " 12	2·7 " 3·1
11·0	11·0	7·5	16 " 20	3·1 " 3·4
13·7	13·7	10·4	25 " 30	3·8 " 4·2
17·5	17·5	13·7	40 " 45	4·4 " 4·8
21·0	21·0	15·4	60 " 70	5·1 " 5·8
24·0	24·0	17·5	100 " 120	6·1 " 6·9

If 16- instead of 10-candle-power lamps be used, three-quarters only of the above number of lamps need be employed; and if 20-candle-power lamps, two-thirds of the above number will suffice to give equal illumination. Arc lamps are not particularly well adapted to the lighting of rooms, unless these latter be very large; on the other hand, they are peculiarly suitable to the illumination of large outdoor spaces, of factories and engineering shops. An arc lamp of 1000 candle-power is sufficient for every 750 to 1000 square yards in cotton-mills, weaving-mills, printing and bookbinding works, and similar establishments. In engineering shops a similar lamp will afford sufficient light for 1500 to 2000 square yards; while in dock-yard and other open spaces a 1000-candle-power arc lamp will illuminate six or seven thousand square yards, and *will suffice* for from twenty to thirty thousand square

yards in street-lighting. In procuring a dynamo for incandescent lighting, a safe rule will be to let the dynamos have a trifle over the E. M. F. that the lamps are marked with, and to allow 1 ampère for every lamp between 48 and 100 volts, 2 ampères for those below 48, and about ·6 of an ampère for those exceeding the 100 volts. For example, an installation of thirty 16-candle-power lamps of 48 volts, each taking about 1 ampère, will be best served by a shunt- or compound-wound dynamo capable of giving 30 ampères at about 50 volts. With regard to motive power, it will be well to allow 1 horse-power for every ten or twelve such lamps; hence a thirty-light installation will need an engine of 2½ horse-power nominal.

66. Although it is not recommended to light lamps for any length of time by batteries, owing to the great cost, and to the inconvenience and labour attendant upon charging, cleaning, and recharging the batteries, yet circumstances may occur which will render their employment compulsory.

For this reason a few details are supplied with a view to giving the cost, the battery most suitable, etc., in these cases. The only battery which is really serviceable, with the exception of the Grove and the Bunsen (which are objectionable in consequence of the noxious nitrous fumes evolved), is the bichromate or chro-

block of carbon sustained on a jointed arm agair which is pressed from below a small carbon rod whi is forced upwards with a given amount of force

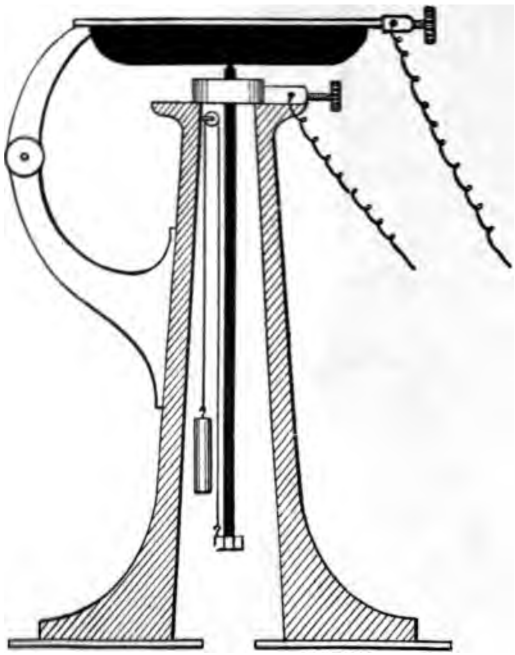

FIG. 43.—WERDERMANN LAMP.

means of a cord passing over a pulley, with a weigh a counterpoise at the other extremity. The carl rod and the carbon block each have attached to th

terminals for connection to the source of electricity. This form of lamp is illustrated at Fig. 43.

Another form of semi-incandescent lamp is that known as the *Soleil,* in which two carbon rods, held at an angle of about 20° from each other by holders through which they can slip easily, rest upon a block of marble or similar substance. As the carbons consume they slip through the holders, and thus maintain the position of the points practically invariable; the presence of the marble softens and diffuses the light. This lamp is illustrated in Figs. 44 and 45.

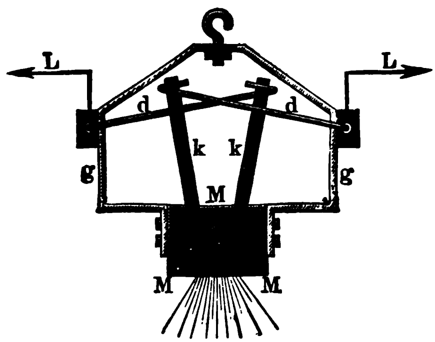

FIG. 44.—LAMP "SOLEIL"—INSIDE.

In practice semi-incandescent lamps have not met with much favour. This is due to the fact that the amount of current and electro-motive force required to produce from them a given amount of light is very

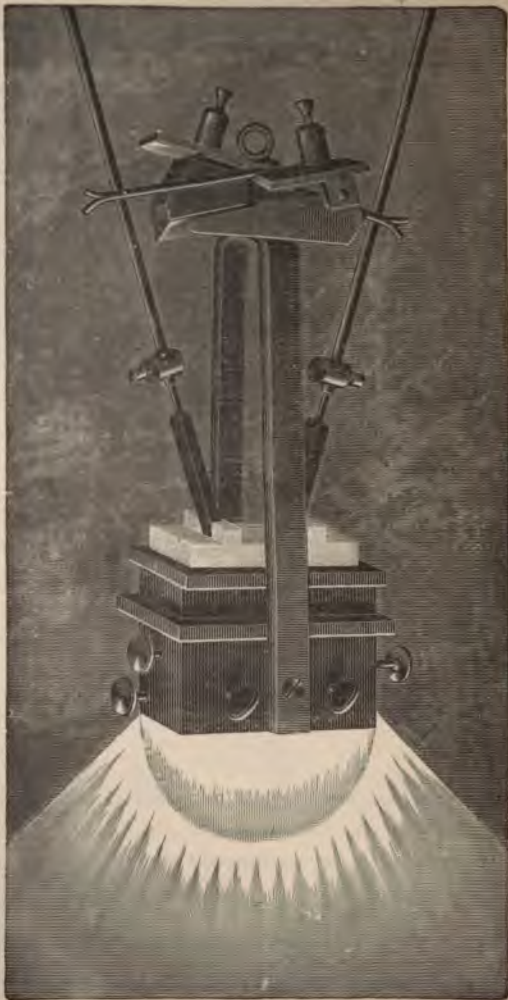

FIG. 45.—LAMP "SOLEIL"—OUTSIDE.

much greater than is the case with arc lamps; while the uncertainty of their action prevents them entering into competition with the purely incandescence lamps, which, although perhaps more costly in maintenance, have the advantage of being singularly steady and trustworthy in action.

The arc lamp has an efficiency of about 2000 candle-power for every 746 watts, or one horse-power, of energy supplied; the incandescent lamps of the best modern construction may be reckoned to give 200, or in exceptional cases 300, candle-power for each 746 watts, or one horse power, expended; while the best of the semi-incandescent lamps (which may be taken as the Werdermann) gives a light of only 700 candle-power for each horse-power (746 watts) of energy supplied.

CHAPTER IV

45. ANOTHER essential appliance in all electrical in-stallations in which the motive power is irregular in speed or in force, or in which it is convenient to apply that power at other times than those at which the light itself is wanted, is the *accumulator*. The accumulator is the outcome of experiments made by Ritter and by Planté which showed that when a current of electricity is passed through water, or other decomposable fluid, into which dip two plates of similar metal or other conductor, the liquid is split up under the influence of the current into its constituent parts; that which is electrically most negative going to the plate which is connected to the source of positive electricity, and that which is most electro-positive being carried to the plate which is connected to the negative terminal. In other words, a strain is set up in the liquid resulting in actual disruption and decomposition; and this state of things lasts as long as the current is supplied. If now the

supply of current be cut off and the two plates be joined together by means of a conducting wire, or any other conductor in the outer circuit, the strain set up by the former passage of the current tends to equalize itself and return to its former level; and in doing this a current of electricity, opposite in direction to that passed through the arrangement in the first instance, is set up and continues with almost unabated force until the separated elements of the fluid have reunited and returned to their pristine condition.

46. The simplest form of accumulator, and one which any amateur can make for himself, is shown in Fig. 46, in which *A* represents a glass jar (a 2-lb. plum-jar will do very well for the experiment). At *B* is a piece of wood, about one inch thick, which, after having been made to fit into and project over the neck of the jar, is placed for a few minutes in melted paraffin-wax to render it at once impervious to water and a non-conductor of electricity. *C* and *C′* are two lead plates, about 6 inches long, 3 inches wide, and $\frac{1}{16}$ of an inch thick, attached one on each side of the wooden cross-bar by means of two or three short brass screws—which must not on any account penetrate so far into the wood as to touch each other, otherwise the current would pass through them instead of going to the outward circuit at all. In the glass jar is placed dilute

68. The reader may feel interested to know what will be the expense of electric lighting by means of the dynamo. This will depend largely upon the motive power employed to drive the dynamo. In places where water-power can be obtained conveniently the water-motor is undoubtedly the cheapest and best form of motor that can be used for driving the dynamo. It would appear that, reckoning 300 working days, 10 hours per diem, the price per horse-power as supplied by water-motors amounts to about $14. Basing our calculation on this rate, and taking the actual electrical efficiency of the horse-power as being equal to 200 candle-power, this gives $3000 \times 200 = 600{,}000$ candle-power hours for $14, or less than $\frac{1}{500}$ cent per candle-power per hour. This of course is not reckoning the depreciation of plant or renewal of lamps, which in this particular instance would amount to more than the cost of the light itself. Only those favoured by locality, however, can hope to get their power so cheaply. The next cheapest source of power is the steam-engine.

For the sake of those who are anxious to get at the actual cost of the appliances necessary and the amount expended in producing the light, the following rough estimate of an installation of 200 lamps of 16 candle-power is appended:—

the wires or poles of the battery to the terminals of the accumulator.

The operation should be continued for some time in order to ensure the retention of any considerable charge. It will be noticed that under the influence of the current bubbles of gas will be given off during the passage of the battery current, these being due to the decomposition of the water. The reason why *two* cells must be used to charge *one* cell of the accumulator is that the water will not split up into its constituent elements (oxygen and hydrogen) unless an E. M. F. of about 2·5 volts be employed; and since none of the batteries mentioned have an E. M. F. of more than 2 volts, it is necessary to employ two cells. The original and first practical form of accumulator devised by Monsieur Planté consisted in two sheets of lead separated from each other by means of a strip of flannel of the same dimensions as themselves, and with an inner strip of the same size to prevent contact when bent, rolled upon a central wooden rod so as to form a tight spiral. A lug or terminal was affixed to each plate, and the whole immersed in a jar containing dilute sulphuric acid (Fig. 47).

47. It was soon found that the power which such a cell acquired of delivering a current of electricity was greatly enhanced by repeated charging and discharg-

ing, especially if the direction of the charging current were frequently reversed; and on examination into the causes of this peculiarity, it was ascertained that they

FIG. 47.—PLANTÉ'S ACCUMULATOR.

were twofold. In the first place, under the influence of the oxygen gas liberated by the charging current, the lead plates get oxidised (*one* only if the current be in one direction only, *both* if the current be reversed) and lose oxygen during the discharge, and in under-

going these repeated charges become more and more spongy; this sponginess extends deeper and deeper into the surface of the plate, until a very large surface is converted into this porous condition. In order to facilitate the formation of the oxide on the lead plates, and to imitate this porous condition without having recourse to "forming" them by means of the current, which of course is costly, many devices having been hit upon and patented by different experimenters. Dipping the plates in nitric or nitro-sulphuric acid to oxidise them; scoring the plates in order to cause them to present a larger surface under the same bulk; punching holes in the plates and filling these with a paste of red lead and sulphuric acid; casting the plates in the forms of grids and filling the interstices with the above-mentioned paste for the positive plate, and with a paste containing litharge (which is a lower oxide of lead) for the negative plate;—all these and more contrivances have been devised to further the desired end. The effect of these contrivances is to shorten very much the process of "forming" the plates; that is to say, of rendering them capable of quickly acquiring a full charge: since the plates which are oxidised are already in a condition to give up oxygen when the strain put upon them by the charging current is relieved. The form used by the holders of

the best patents, namely, the Electric Power Storage Company, and Messrs. Elwell and Parker, consists in lead plates cast in the shape of grids, 8½ inches wide by 9½ inches high and $\frac{3}{16}$ of an inch in thickness, having the perforations of the positive grids filled with a stiff paste of minium, while the negative grids are filled with a paste of litharge. These plates are arranged in close proximity to the cells, but sufficient space is secured to ensure free circulation of the acid and to prevent any chance of short-circuiting (either through buckling of the plates or by accidental detachment of pieces of the paste) by means of separating-pieces of celluloid, vulcanite, or India rubber. In most cases more than one positive and one negative plate are used in these cells, seven being the smallest number usually sent out by the above-mentioned makers, and thirty-one the largest: and in these cases the separate plates are *burned* together to a common junction-piece of lead, one for the negative and one for the positive; which pieces form the terminals of the accumulator. When an accumulator has been fully charged, either from a battery or an appropriate dynamo, it is found to give at the start an E. M. F. of 2·4 or 2·5 volts, which however rapidly falls until it reaches 2 volts, at which point it remains steady until the cell is nearly discharged, when it again falls to 1·9 or even less; and

since it is not advisable (in order to keep the cell in good working order) to entirely discharge an accumulator, it is well to cease discharging and recommence charging when the E. M. F. of any cell falls 1·9 volts. The capacity or amount of current which a charged accumulator can give depends entirely upon the surface presented by the positive plate or plates, and this capacity is generally reckoned in ampère-hours. By ampère-hours is understood the number of hours that a given cell can supply a current of 1 ampère, or the number of ampères that such a cell could supply for an hour.

For instance, a cell said to have a capacity of 60 ampère-hours would be capable of supplying a current of 1 ampère for 60 hours, of 2 ampères for 30 hours, of 4 ampères for 15 hours, of 8 ampères for 7½ hours, etc., or indeed of any factors of hours and ampères which multiplied together would give 60.

The earlier accumulators in which the plates were "formed" by electrical means alone, owing to the comparatively slight depth to which the changes in the lead took place, and therefore the limited surface of the active material, were capable of supplying only about 3 ampère-hours for each square foot of positive lead surface: in the best forms of modern accumulators, in which the forming is to a great extent produced

chemically (by pasting), the capacity is not less than 6 ampère-hours per square foot of positive surface. This is equivalent to 2 ampère-hours and 4 ampère-hours, respectively, per pound of lead employed. Even this has been exceeded by lightening the plates, as is done when the accumulators are required for traction purposes or launches, and in these cases as many as 5 ampère-hours have been got from each pound of lead.

48. Whatever be the number of accumulator-cells which have to be charged, if they are connected in *series* (that is to say, the negative terminal of the one cell connected to the positive terminal of the next, and so on), the E. M. F. of the charging current must not be less than 2·5 volts per cell (see §46). It is not necessary that it should be in excess, and it is not desirable that it should greatly exceed this. The specific gravity of the acid which is used in the cell should be about 1·22 when the cell is fully charged; and it is necessary that the specific gravity of the acid should be taken by means of a hydrometer, and should not be less than 1·15 before charging. Any deficiency or excess must be made good, either by the addition of water in the former case, or by the addition of sulphuric acid in the latter. The charging current should be about 10 ampères. When the cells are fully charged the appearance of the liquid generally denotes this pretty

accurately, by assuming a milky appearance, dependent on the extrication of myriads of little bubbles of liberated gas not taken up by the plates. It is not advisable to charge cells with too large a current, nor yet to draw off too large a current from them, as in either of these excessive cases the plates themselves become injured by buckling, and by the paste which fills the interstices falling out. It is not absolutely necessary to charge a given number of cells in *series.* If the electro-motive force of our dynamo, for instance, were only 12·5, we could not possibly charge ten cells coupled in series, since the least E. M. F. required to effect this at 2½ volts per cell would be 25 volts; but if we coupled the ten cells in five sets of two in *parallel* (that is to say, the positive plates of the one cell connected to the positive plate of the next, the negative plates of each cell being connected likewise), and then connect these five sets in *series,* then, since the ten cells constitute virtually but five large ones, they can be fully charged by the above-mentioned dynamo.

But it must be noted that although it is possible by grouping cells in parallel to charge them with a lower electro-motive force than if they be connected in series, yet either the *amount of current* supplied must be increased in proportion to the number of

groups of cells in parallel, or else the *time* allowed for charging must be increased in like proportion. As a farther example, let us suppose that it be possible to charge ten cells with a current of 10 ampères at a pressure of 25 volts in 3 hours. If we arrange the cells in five sets of two in parallel we can charge with an E. M. F. of 12·5 volts, but shall require a current of 20 ampères to do the same work in 3 hours, or else to supply a current of 10 ampères for 6 hours.

Accumulators like all other human productions are subject to imperfections. We have noticed the buckling of the plates and the falling away of the paste; we may now direct our attention to what is called *sulphating*—that is to say, the production of white patches of sulphate of lead which is entirely inactive, and which greatly detracts from the efficiency of the plates. When once sulphating sets in, the tendency to increase is very strong. The best way to prevent this defect is never to run the cells down too much, to keep the acid of the right strength, and above all to keep the cells fully charged. The addition of about one part of sulphate-of-sodium solution to every five parts of strong sulphuric acid in the charging liquid goes a great way towards the prevention of sulphating.

Owing to the moisture condensing on the outside of the cells themselves, and to the fact that this moisture

is itself a conductor of electricity, there is a great tendency in a charged cell, or in a number of charged cells placed in vicinity, to *electrical leakage;* in other words, the current which the cell ought to supply, instead of being retained or passing through the conductors to the desired work, finding a shorter circuit down the outside of the cells themselves, leaks away through this shorter passage and is lost for any useful work. Varnishing the cells or coating them with vaseline or paraffin-wax and standing them on little insulating cups filled with resin-oil are good preventives of this leakage; and cases have been known in which charged cells have retained their charge for three and even four months.

49. In reckoning the number of cells required to light up a given installation it should be borne in mind that two points must be taken into consideration. The first is the voltage of the lamps which are to be employed; and the second, that the number of the cells to be used will have to be the same to suit this voltage, whether *one* or *many* lamps constitute the installation. For instance, if we desire to put up an installation consisting of 120 lamps of 50 volts, and another consisting of a single lamp of 50 volts, the number of accumulators to be used in either case will be 25, since it takes 25 cells each giving 2 volts to supply the necessary

pressure of 50 volts. But there will be a great deal of difference in the *duration* of the light supplied by the 25 cells in these two cases. Since each lamp taking 50 volts will require about 1 ampère of current to maintain its light at full efficiency, it follows that the 120 lamps will run off a current of 120 ampères, while the single lamp is only absorbing 1 ampère. This leads us to the second point, namely, that the capacity or size of the cells (which decides the number of ampère-hours that the cell can give) should be such as to be able to furnish the necessary amount of current for the desired time. In looking over the makers' lists of accumulators we find that the number of ampère-hours which can be supplied by the different sizes of cells varies from 130 in the smaller sizes to 660 in the larger. Referring again to our typical example of 50-volt lamps, if it were desired to keep a single lamp lighted for 8 hours, 25 cells having a capacity of 8 or 10 ampère-hours would be ample; whereas, were it necessary to maintain the light of the 120 lamps for 8 hours, since 8 × 120 are 960, 25 cells each having a capacity of 960 ampère-hours would be needed.

It is well also to remember in making these calculations that the conductors or "leads" present some resistance and absorb some current; so it is necessary to allow for this by adding a cell or two to overcome this

ACCUMULATORS: TABLE OF THEIR DIMENSIONS, CAPACITY, WEIGHT, ETC.

Description of Cell.			Acid for each Cell.		Working Rate.		Capacity. Ampère-Hours.	Approximate External Dimensions.				Weight of Cell complete with Acid.
Type.	Number of Plates.	Material of Box.	Weight of Acid.	Part of Carboy.	Charge Ampères.	Discharge Ampères.		Length.	Width.	Height.	Height over all	
			lbs.					ins.	ins.	ins.	ins.	lbs.
L	7	Teak	18	·16	10 to 13	1 to 13	140	5¼	11	17¼	19¼	74
		Glass	22	·20	10 " 13	1 " 13	140	5	11½	14½	15¾	68
	11	Teak	25	·22	16 " 22	1 " 22	220	7¼	11	17¼	19¼	107
		Glass	32	·29	16 " 22	1 " 22	220	7½	11½	14½	15¾	101
	15	Teak	35	·32	25 " 30	1 " 30	330	9¼	11	17¼	19¼	141
		Glass	38	·35	25 " 30	1 " 30	330	9¼	11½	14½	15¾	128
	23	Teak	53	·47	38 " 46	1 " 46	500	14¾	11	17¼	19¼	228
		Glass	54	·49	38 " 46	1 " 46	500	14	11½	14¾	15¾	211
	31	Teak	70	·63	50 " 60	1 " 60	660	19¾	11	17¼	19¼	286
		Glass	73	·66	50 " 50	1 " 60	600	18¼	11½	14¾	15¾	265
C	9	Teak (with lid)	8·4	·075	6 " 8	1 " 8	72	6	13¼	6¾	7¼	38
	15	Teak (with lid)	14·0	·13	12 " 14	1 " 14	136	9¼	13¼	6¾	7¼	62
T	11	Teak (no lid) .	10	·08	16 " 20	1 " 20	66	6¾	8¾	11¼	13¼	37
		" (with lid)	10	·08	16 " 20	1 " 20	66	6¾	8¾	11¼	13¾	38
		Ebonite (no lid)	10	·08	16 " 20	1 " 20	66	6	7¼	11	12¾	40
	15	Teak (no lid) .	14	·12	24 " 28	1 " 30	95	8¾	8¾	11¼	13¼	52
		" (with lid)	14	·12	24 " 28	1 " 30	95	8¾	8¾	11¼	13¾	53
		Ebonite (no lid)	14	·12	24 " 28	1 " 30	95	8	7¼	11	12¾	42
	19	Teak (no lid) .	18	·16	30 " 35	1 " 40	120	11	8¾	11¼	13¼	65
		" (with lid)	18	·16	30 " 35	1 " 40	120	11	8¾	11¼	13¾	66
		Ebonite (no lid)	18	·16	30 " 35	1 " 40	120	10¼	7¼	11	12¾	54
	23	Teak (no lid) .	22	·20	38 " 42	1 " 50	145	13¼	8¾	11¼	13¼	79
		" (with lid)	22	·20	38 " 42	1 " 50	145	13¼	8¾	11¼	13¾	80
		Ebonite (no lid)	22	·20	38 " 42	1 " 50	145	12¾	7¼	11	12¾	66
V	4-cell Battery	Teak	4·8	·044	2 " 4	1 " 4	18	9	8¾	13¾	15¼	54
	8-cell Battery	Teak	9·6	·088	2 " 4	1 " 4	18	16¾	9¼	13¼	13¾	104

The E. M. F. of each cell when discharging is 2 volts for all sizes. When charging, each cell requires an E. M. F. of 2·5 volts.

CHAPTER V

50. WE shall now consider some of the smaller appliances which are needed for the sake of convenience in connecting up the supplier of electricity, be it battery, accumulator, or dynamo, with the lamps, etc., where the electricity is utilised. The first that demand our attention are the main conductors themselves, generally called "leads," which may consist either in single copper wires of sufficient section to carry the current safely (see § 27), or of a cable, made of a number of strands of finer wires, which in its entirety is equivalent in conducting power to the single copper wire. A table of the stranded cables usually supplied, with their safe current-carrying capacity, is given on page 124.

51. The branch wires which lead from the mains to the lamps need not, of course, be as heavy as the mains. These latter must be of such a gauge as to be able to carry the whole of the current passing from the dynamos to the whole of the lamps; whereas the

GENERAL TABLE OF THE PROPERTIES OF STRANDED CABLES.

No. of Wires in Strand.	B. W. G. of each Wire.	Diameter of each Single Wire.	Equivalent Solid Wire B. W. G.	Diameter of Equivalent Solid Wire.	Weight of Strand per Statute Mile.	Resistance of Strand per Statute Mile.	Absolute Safe Working Current.
		inch.		inch.	lbs.	ohms.	ampères.
3	25	·020	20½	·034	19	46·79	1
3	23	·024	18½	·042	28	32·50	2
3	22	·028	18	·049	38	23·87	3
7	25	·020	17	·053	45	20·01	5
7	23	·024	16	·064	65	13·89	6
7	22	·028	15	·075	89	10·20	7·5
7	21½	·030	14	·080	102	8·893	10
7	20½	·033	13½	·088	124	7·342	11
7	20	·036	13	·096	147	6·175	13
7	19	·040	12	·107	182	5·002	16
7	18	·048	10	·128	262	3·473	24
7	17	·056	9	·149	356	2·552	32
7	16	·064	7½	·171	465	1·953	44
7	15	·072	6	·192	589	1·543	54
7	14	·080	5	·213	727	1·253	66
19	20	·036	8	·159	402	2·261	36
19	19	·040	7	·176	496	1·831	45
19	18	·048	5½	·211	715	1·271	66
19	17	·056	3½	·247	973	1·079	90
19	16	·064	2	·282	1270	·7154	120
19	15	·072	1½	·317	1608	·5652	140
19	14	·080	00	·352	1985	·4579	187
19	13	·092	0000	·404	2625	·3462	300
19	12	·104	000000	·458	3354	.2709	375
37	16	·064	0000	·394	2482	·3661	350
37	15	·072	00000	·443	3142	·2892	350
37	14	·080	0000000	·493	3879	·2343	375
37	13	·092	. . .	·566	5130	·1772	375
37	12	·104	. . .	·640	6555	·1386	700
61	13	·092	. . .	·728	8477	·1072	750
61	12	·104	. . .	·823	10832	·0839	1000

This is reckoned on a basis of 1494 ampères to each inch in diameter.

branch lines need only be of such a gauge as will carry the current required by the particular lamp or lamps which they supply. It is usual to run arc lamps in series, as shown in Fig. 29*a*, though sometimes they

ɔe arranged in parallel, as shown in Fig. 30. In-scent lamps are almost always arranged in parallel, ›wn in Fig. 30, though of course, if the resistance : individual lamp is less than the electro-motive demands to produce the required current through they may be arranged partly in parallel and · in series, by which means the desired resistance ɔe obtained. Semi-incandescent lamps may be

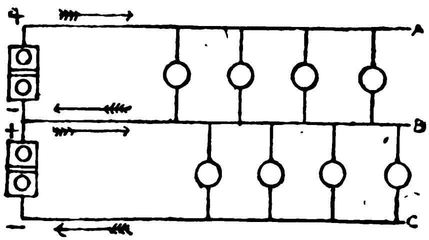

FIG. 48.—THREE-WIRE SYSTEM.

worked with a separate circuit for each lamp, or ɔupled in series as in Fig. 29. There is another of coupling up a considerable number of lamps o dynamos by the employment of three wires for this reason called the "three-wire system," , although not much used except in the case of installations, must be mentioned here. This is ated in Fig. 48, where *D* and *D'* represent two ɪos with their nearer positive and negative ter-

minals connected together and also to a central lead or conductor *B*, while their outer positive and negative terminals are respectively connected to the leads *A* and *C*. The lamps are arranged in parallel across the conductors *A* and *B*, and *B* and *C*. Here we see that the current issuing from dynamo *D* passes along the conductor *A*, crosses over through the lamps to the lead *B*, and could return to the dynamos through this lead. We also see that this same lead *B* receives the outcoming current from the dynamos *D'*, whence it passes across the lower row of lamps to the conductor *C* on its return to the dynamo. It will be quite evident that if the number and resistance of the lamps on either side of the conductor *B* are equal, no current really passes along that conductor either to or from the dynamos; since the return current from the one and the outgoing current from the other would exactly neutralise each other, so that the main *B* might be detached from the dynamos without any variation in the final result. But when the number of lamps or the resistance on the one side exceeds that on the other, this central conductor *B* when connected with the dynamos acts as a compensator and carries the difference in the amount of current. The adoption of this plan enables the operator to use three cables instead of four; and as the heavy leads which are necessary in

large installations are very expensive, the saving thus effected is of considerable importance.

52. We now pass to "switches," which are in electrical work what stop-cocks, faucets, and taps are in water-works. In other words, they are the appliances by means of which the current can be turned on or off, or subdivided into many channels. Of "switches" there are many kinds. First, those which simply cut off or turn on current in one direction only; second, those which can turn on current in two or more directions; third, those which work automatically, cutting off the current when it reaches to a certain number of ampères or when it falls below a certain number of ampères.

The "switches" themselves, like the "leads" or cables which carry the current, must have their parts made of metal of sufficient substance to carry the desired current without heating; and in the case of heavy currents special precautions must be taken in their construction to prevent heavy sparking when turning the current off and on, otherwise the points of contact soon become badly corroded, and perfect contact is not obtained; to the great detriment of the efficiency of the instrument, and actual danger in many cases.

53. The simplest form of "switch" is that shown in

Fig. 49, in which two binding-screws are screwed as terminals onto a block of wood, the one binding-screw having below it a fixed block of metal, the other a sliding lever-arm, also of metal. This movable arm travels in the segment of a circle, between the fixed metal block and a pin which limits its play. When the movable lever is on the metal block, as there is perfect contact between the two terminals, the current

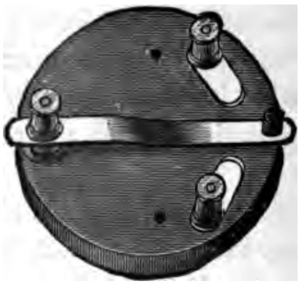

FIG. 49.—SIMPLE SWITCH.

flows without let or hindrance; but when the lever-arm is placed against the pin, as there is no connection between the two terminals no current flows. Small switches of this kind are useful between the mains and separate lamps; but where a large current has to be carried, heavier switches of a more complex character are requisite. A very good form of main switch is shown in Fig. 50, in which two metallic rings built up

of pieces of copper of unequal length, bent so as to leave gaps at their free extremities as shown in the figure, are screwed one at each end of a terminal board; in the centre is a trunnion which carries pivoted at its extremity a cross-piece of bronze or copper, so arranged that its projecting pieces fit into the gaps in the two side pieces. When the handles stand in a line

FIG. 50.—DRAKE & GORHAM SWITCH.

with the two metallic rings, the current runs right through the arrangement; but when the handles are turned sufficiently to the right or to the left, the prolongations of the central movable plate disengage themselves from the gaps in the two lateral rings, contact is broken, and the current ceases to flow.

Another form of switch very similar in action to the

first described is that illustrated at Fig. 51, in which a number of springy copper strips, bent into a bow, are pivoted to the centre of the terminal board, and actuated by a handle, the copper strips making metallic contact with metal plates attached to opposite terminals, over which the bent ends of the strips travel. When the handle is turned on one side, the strips rest

FIG. 51.—W. & R. LARGE-CURRENT SWITCH.

on a piece of ebonite or other non-conductor, and consequently no current passes; when, on the contrary, the strips rest on the metal plates, the circuit is complete through the strips to these plates, hence the current flows. It will be evident on consideration that if one of the metal plates in the last instance were divided into two or more sections, each section being connected to a separate binding-screw or terminal, it

would be possible by turning the handle more or less, so as to cause it to rest on one or the other of these separate sections, to send the current along any particular circuit connected to *that* binding-screw which happened to be in contact with the particular plate on which the strips were temporarily resting.

This leads us to the consideration of *two-way* and *multiple-way* switches, one of which is shown in Fig. 52.

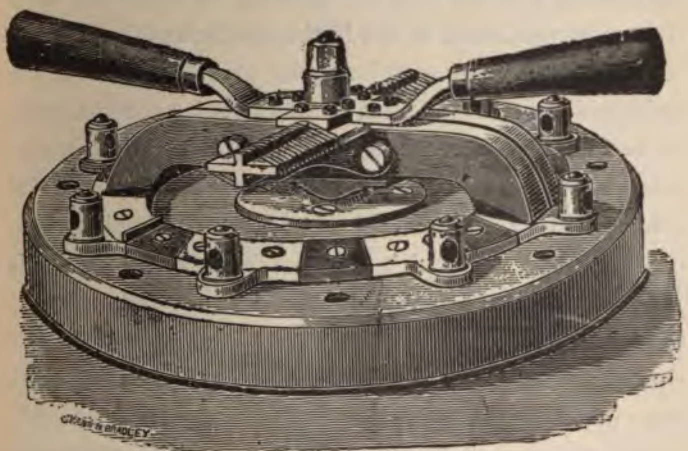

FIG. 52.—MULTIPLE-WAY SWITCH.

The illustration almost explains itself. The central handle carries the spring contacts, which pass over separate metal plates connected with different circuits. The ingenuity of inventors has displayed itself in many

ways to produce switches which shall ensure good contacts and obviate sparking as much as possible. In some cases attempts have been made to introduce, gradually, varying resistances, so as to reduce the current from its full amount to a minimum, while turning the handle from *on* to *off*, so as to render the switch absolutely sparkless; in others, springs are adapted to the handle so that the switch cannot be left accidentally half on or half off (this is necessary to avoid the accidental formation of an arc in the switch itself); in other cases, safety *fuses* consisting of given lengths of tin wire which melts and thus breaks circuit automatically, if too heavy a current is passing, are included in the circuit of the switch. But the instruments described above will give the intelligent reader a sufficient idea of the mode in which all switches work. There is another form of connector known as a "plug switch," which, as the name indicates, completes circuit by the insertion of a metal plug in a conical hole between two metal plates.

All these switches, but more especially those intended to carry heavy currents, should be carefully insulated. The bases of the smaller ones (those not carrying more than from 1 to 5 ampères) may be of well-seasoned mahogany boiled in melted paraffin-wax, or of ebonite; but those carrying the heavier

currents on the main circuit, say from 5 to 50 ampères and upwards, should be mounted on slate bases, to prevent any accidental firing through sparking or otherwise. According to the Board of Trade regulations, "switches," "commutators," etc., must be mounted on incombustible bases, and when the handle is moved or turned to and from the positions of "on" and "off" it should be impossible for it to remain in any intermediate position, or to permit of a permanent arc or of heating; also that the handle of every switch must be completely insulated from the circuit.

54. We have noticed in speaking of lamps that incandescence lamps have either platinum loops left at one extremity for connection to the conductors, or else collars (either of *vitrite*, which is a kind of black glass, or else of brass) with two brass plates at their upper surface by which connection can be made. Neither of these systems alone is suitable for attachment to the leads without the intermediation of some kind of holder, and the holders themselves (except in a very primitive form of installation) are not sufficiently elegant or convenient for general use. For this reason brackets or pendants must also be employed. These do not differ very greatly in outward appearance from those employed by gas-fitters, the chief difference being, of course, that the hollow part of the stem

which in ordinary gas-brackets permits the flow of gas, serves in the electric bracket to carry the wires which convey the current to the lamps. We illustrate in Fig. 53 the pattern of holder mostly in use

FIG. 53.—EDISON-SWAN SPRING HOLDER.

for bottom-loop lamps. *A* represents the Edison-Swan spiral-spring holder, in which two terminals on the outside of a circular wooden base communicate with two central hooks which enter into and serve to hold the loops of the bottom-loop lamps. In order to secure firm contact and yet to allow easy detachment

and replacement of the lamp, a spiral spring of brass or other elastic wire surmounts the wooden base. Usually there is a conical prolongation at the other extremity of the wooden disc which, being furnished with a screw-thread, enables the holder to be screwed into any desired place.

Another modification of this holder is seen in Fig. 54, in which, instead of having the spiral spring at the

FIG. 54.—DOUBLE-LOOP HOLDER.

upper surface of the holder, to maintain firm contact between the hooks and the loops, a couple of cross-loops of springy wire are substituted. In the Woodhouse-Rawson form of holder elasticity is given to the two hooks by forming their lower extremities

[illegible] tight spiral and placing a collar with three upright brass springs at equidistant points round the lower portion of the holder. This is shown in Fig. [illegible]. The elasticity of the hooks and the springiness of

Fig. [illegible].—Woodhouse-Rawson Holder.

the three lateral brass pieces renders this a very efficient holder; but if the three brass springs are long, so as to project somewhat over the surface of the lamp, they cut off a certain amount of light. Sometimes these holders are furnished with a flange or extension by means of which a lamp-shade can be supported about the upper rim; in other forms the holder itself screws into an extension which serves the same pur

pose. In order to render these holders suitable for lamps having brass collars, a modification known as

FIG. 56.—BAYONET HOLDER.

the bayonet-joint holder is constructed. The body consists of a wooden or ebonite core to which are attached on one side the terminals connected to two spiral

springs: on the other side the core is surrounded with a brass collar having two slots cut in it at diametrically opposite points, which slots, after going in a straight line for about half the length of the collar, make a rectangular bend. This is shown in Fig. 56. By this device, when the lamp is pushed into the collar (care being taken that the pins on the lamp collar coincide with the slots in the holder) and then turned to the right when it reaches the bend, the lamp is held firmly in its place by the pressure of the two springs, which at the same time make good electrical contact with the brass semicircles at the top of the lamp. In some few instances sockets are screwed over these holders. Some holders are made in which a switch is introduced, by means of which the current can be cut off at the lamp itself; but this is neither very convenient, nor a very usual practice.

55. It may happen in large installations, owing to a breakdown in some of the lamps, or accidental short-circuiting, that too large a current may be travelling along a given lead or to a given lamp. This may be productive of danger in the shape of fire, if the conductor thus called upon to carry the excessive current should overheat, or even melt, or at least "burst" *

* "Bursting the lamp" is the technical name given to the disruption of the carbon filament under the influence of an excessive current.

the lamp. To avoid these risks, it is usual to place at different points of the circuit, where ramifications occur, short pieces of *tin* wire of such a diameter as will carry safely the normal current, but which will instantly melt and disconnect the circuit when the current exceeds the normal. The technical name for these devices is "safety cut-outs" or "safety fuses." In order to increase the sensibility of the cut-out, so as to cause the wire to break even before the excess of current causes it to reach the melting-point, the simple expedient of stringing a leaden bullet to the centre of the tin wire has been found remarkably efficient. Fig. 57 illustrates this device. As soon as the temperature

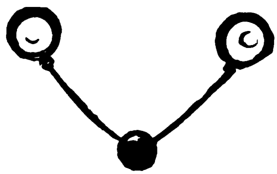

FIG. 57.—COCKBURN'S FUSE.

of the tin wire becomes exalted by the passage of an excessive current, the wire stretches under the pull of the bullet and breaks without melting.

56. In those cases in which it is necessary that the limit which the current may safely reach shall be very accurately and sharply defined, a form of cut-out

which depends on the increasing magnetism impa
to an electro-magnet by an increase in current is of
adopted. This is known as the *Cunynghame* cut-o
and consists, as is shown in Fig. 58, of a pivoted re

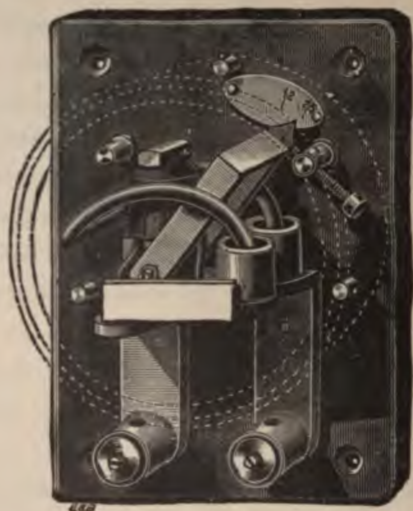

FIG. 58.—CUNYNGHAME CUT-OUT.

angular iron bar, carrying at its two sides quadrants of brass wire which dip into two mercury-cups connected to the terminals of the main circuit and so arranged that the current flows round the coils of an electro-magnet the poles of which face this iron rectangular bar and tend to pull it towards them, and in so

doing to raise the wire quadrants out of the mercury-cups. By means of an adjusting screw the distance of the rectangle from the electro-magnet can be regulated to a nicety. When the normal current is flowing, this rectangle is adjusted so that the electro-magnet shall not be sufficiently near to raise the wires and break the circuit, but shall do so directly the current reaches the number of ampères at which it is desired to break the circuit.

57. We need now only mention two other useful, we might almost say necessary, adjuncts to every installation of any considerable size; these are the *ammeter* and the *voltmeter*. As the name implies, the ammeter is a measurer of current in ampères. There are in trade at present almost as many varieties of ammeters as of clocks and watches, but they may be all conveniently divided into two great classes, namely: those in which a permanent magnetic needle carrying an index is deflected out of its normal position when a current is passed over or under it, through a conductor forming part of the instrument, which deflections increase with the increase of current; or those in which no permanent magnetic needle is employed, but a solenoid is caused to attract a soft iron core during the passage of the current (the attraction increasing with the increase of the current), and by so doing

registers the amount of attraction, and consequently the strength of the current, by means of appropriate devices connecting the core to an index which denotes on a dial the extent of attraction and the value of the current. Instruments of the former class are generally

FIG. 59.—JOEL PATERSON AMMETER.

very delicate in their registrations, and are suitable for measuring currents produced by batteries. But they are liable to three defects. Firstly, masses of iron or magnets or dynamos in their vicinity, by affecting the magnetic needle, falsify their readings and vitiate the results. Secondly, since the deflections do not increase

ually with the increase in the current, but rapidly ll off as the needle passes out of the sphere of the nductor's influence, it is impossible to get a large imber of graduations which shall be legible. Thirdly, e magnetised needles themselves are subject to ıanges in their magnetic strength, which renders it :cessary to "recalibrate" * frequently if any degree of :curacy be required.

A sketch typifying the construction of this form of nmeter is given in Fig. 59. In order to overcome ıe defects above mentioned, and to fit the instrument ır use in the vicinity of dynamos, the magnetised ›edle is replaced by a piece of soft iron which is ther sucked into a solenoid or attracted by an electro-ıagnet, as previously described. Fig. 60 exemplifies ne of the best forms of these non-magnetic ammeters. 'his is known as the gravity ammeter. It consists in tongue of very thin, soft sheet-iron *B* of the shape of scythe with its handle; this is delicately suspended at ne extremity so as to swing freely, and is furnished ith an index or pointer by means of which any varia-on in position is indicated on a graduated dial over hich the extremity of the pointer passes. The blade f the scythe-shaped piece of iron enters partly into

* Recalibrate—to verify the readings of the instrument.

a solenoid *A* fixed vertically over its end. Wh current is passed through the coils of this sc from the terminals *T T′*, the scythe-shaped p iron is drawn up into the hollow core of the so

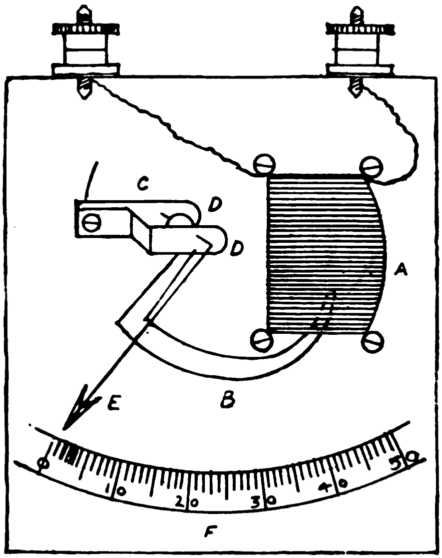

FIG. 60.—GRAVITY AMMETER.

and as the attraction increases with the increase current, the piece is drawn farther in as the increases, and the amount of attraction and quently the strength of the current is indicated graduated dial.

It must be observed that in making these instruments, the wire with which the solenoid is wound must be of such a section as to carry without appreciable heating rather more than the heaviest current that the instrument is intended to measure. As these ammeters, from the nature of their construction, present but very little resistance to the passage of the current, it is usual to place them in the direct circuit with the dynamos, etc., and lamps, so that the amount of current passing through the entire installation can be at any time read off with the same facility as that with which an engineer reads the steam-pressure by means of a Bourdon gauge.

58. The voltmeter, or measurer of electrical pressure in volts, is constructed in precisely similar mode to the ammeters above described, with this difference only, that the wire used to wind the bobbins or solenoids (according to the class to which the instrument belongs) is very fine—so fine, in fact, as to present a very great resistance to the passage of the current. It is usual to allow in this wire a resistance of 50 ohms for every volt to be measured. Hence a voltmeter to measure 10 volts should have coils presenting a resistance of 500 ohms; an instrument to measure 100 volts, 5000 ohms; and so on. The reason for this is that since we measure the pressure by the amount of current which

can be forced through the instrument, we must construct this latter of so high a resistance that the internal resistance of the source of electricity, be it battery or dynamo, shall be so small when compared to that of the voltmeter itself, that its influence may be practically neglected.

To elucidate this, let us suppose that we constructed a voltmeter having practically *no resistance*, and that we tested successively two Daniell cells, one having an internal resistance of 5 ohms and the other of only 1 ohm; it will be evident from Ohm's law that, although the E. M. F. of these two cells would be exactly the same, yet, since the resistance of the smaller cell is five times greater than that of the larger, the latter would send five times the amount of current round the coils of the said voltmeter and consequently would give an indication of five times the value. This of course would be a false reading, since the voltage would be the same in both cases. But suppose that the voltmeter were wound with coils having a resistance of 250 ohms: it is quite evident that the difference in the total resistance when using the cell having 1 ohm resistance compared with the one having 5 ohms resistance will amount to only 4 parts in 255, or rather less than 2 per cent. Consequently a voltmeter wound to such a resistance can be depended

upon for giving true readings with such a variation in the internal resistance of the generator as 1 to 5 ohms, and greater accuracy if, as is the case with most dynamos, the internal resistance be smaller.

Figs. 61 and 62 illustrate two forms of voltmeter.

FIG. 61.—VOLTMETER (WALSALL).

The voltmeter, owing to its great internal resistance, cannot be placed in direct circuit with the battery or dynamo and the lamps, etc., since it would practically cut down the current to nothing; it is generally connected in shunt with a dynamo, etc., and corrections made for the resistance of the other parts of the circuit; or if it is desired to take the voltage either of

FIG. [illegible].—VOLTMETER (CARDEW'S).

:ery or of a dynamo by direct reading, the volt- is connected in the main circuit, and the other n is disconnected or switched off.

: voltmeter is extremely useful for obtaining liate information as to the efficiency in E. M. F. battery, accumulator, or dynamo in use, and the ter is no less useful in indicating the current. y happen that a battery, etc., may denote by the eter that it is giving its proper E. M. F., which ting with the ammeter denotes a great deficiency rent, which may be due either to imperfect con- n, to the corrosion at the points of contact, or to e along the line.

CHAPTER VI

59. An electric motor is a machine whereby electrical energy in the form of current can be transformed into mechanical energy in the form of motion. In this it is the exact opposite of the dynamo, in which mechanical energy in the form of motion is converted into a current of electricity. In point of fact, any well-made dynamo capable of supplying current when put into motion by the application of external force, will, if supplied with a current of electricity, rotate, and by its rotation give motive power. Nearly all the dynamos previously described can be, and actually are, employed as motors; the only difference being in their requiring to be fed from a source of electricity, and provided with means in the shape of bands, cogs, etc., to transmit the energy which they are furnishing.

It is clear from the above statements that the electric motor cannot be looked upon as a producer of energy; *it is simply a converter.* Here it is that its special

value is most important. Given a source of power at a spot inconvenient or impossible, in the ordinary mode, of application to any useful purpose, yet if we can utilise this power for the production of electricity by means of a dynamo on the spot, we can convey this electricity to any reasonable distance by means of copper wires or other similar conductors to any desired place, and there by means of an electric motor utilise it by reconverting it into the energy of motion. Of course loss is entailed in the process of the conversion of mechanical energy into electricity, and back again from electricity into mechanical energy. We have already seen in the case of dynamos (§ 21) that this loss in the best modern dynamos varies from 2½ to 5 per cent; in the case of electric motors the percentage of loss is greater, amounting to as much as 20 per cent in the larger motors, and rising to 50 or even 60 per cent in the smaller.

60. It will not be necessary here to enter deeply into the details of construction of the electric motor; one typical form will be described, and we shall content ourselves with presenting illustrations of a few of the more important forms. The electric motor, then, consists in a carcase of soft iron furnished with projecting pole-pieces, between which an armature can rotate. Almost any shape can be given to the carcase to suit

the particular exigencies under which the motor may be called to act, but in any case it must constitute an

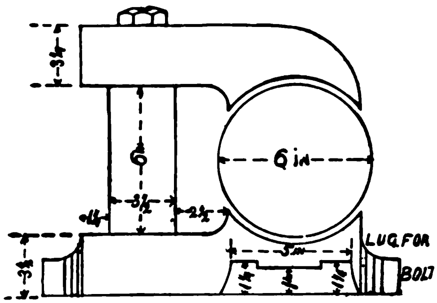

FIG. 63.—SIMPLEX MOTOR (BARE).

electro-magnet, and have one portion at least wound with wire, in order that the current supplied to the motor should convert it into an electro-magnet.

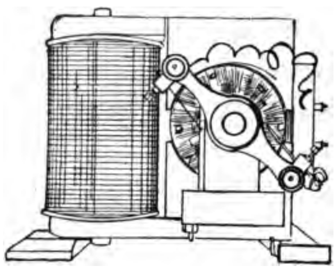

FIG. 64.—SIMPLEX MOTOR (WOUND).

The form depicted in Figures 63 and 64 from its simplicity is known as the *Simplex*. Here we have a soft

iron core wound with wire and furnished with projecting pole-pieces. Between these pole-pieces, and supported by bearings, is an armature of soft iron wound precisely as described in the section devoted to the dynamo, and which may take the form either of the Siemens H, of the "drum," or of the "ring" type, the two latter being specially adapted to those motors which are to be self-starting when the current is turned on. This armature is shown in place in Fig. 64. On the same shaft with the armature is the commutator, to which the ends of the coils with which the armature is wound are duly connected. On this press lightly two springy brushes, which serve to distribute the electricity supplied to the binding-screws, from the source, to both armature and field-magnet. When the current is turned on, the field-magnet becomes powerfully magnetic, one end becoming north and the other south, and imparts similar polarity to the projecting pole-pieces. At the same time the current, in passing round the coils of the armature, converts it into an electro-magnet having its poles at right angles to the poles of the projecting pole-pieces. It will be noticed that on causing the ring to rotate between the brushes, although the iron mass of the ring with its accompanying coils of wire moves round, yet as the brushes remain always at the same point and press consecu-

tively on the different sections of the commutator only which lie directly under them, the north and south poles of the armature remain always at the *same points*, viz., *just in a line with the brushes.* Now it will be quite evident that when such an armature, thus magnetised, finds itself between the poles of an electro-magnet as figured in our last illustration, the right-hand half of the armature, being thus kept continually *south*, will be continuously *attracted* by the *north* pole of the electro-magnet, and as continuously *repelled* by the *south* pole of the electro-magnet. At the same time the left-hand half of the armature, being *north*, will be continuously *repelled* by the *north* pole of the electro-magnet, and as continuously *attracted* by the *south* pole. As these four attractions and repulsions are all tending to move the ring in the same direction, the armature, if free to move, begins to rotate; and as, like the donkey with the cabbage suspended from its own head, its attracted portion can never get any nearer the point of attraction, so the armature keeps up a continuous rotation as long as current is supplied. It is on this principle that all motors using continuous currents are based.

There are other forms of motor specially constructed to work with alternating currents (see § 16), but hitherto no great success has attended the application of alter-

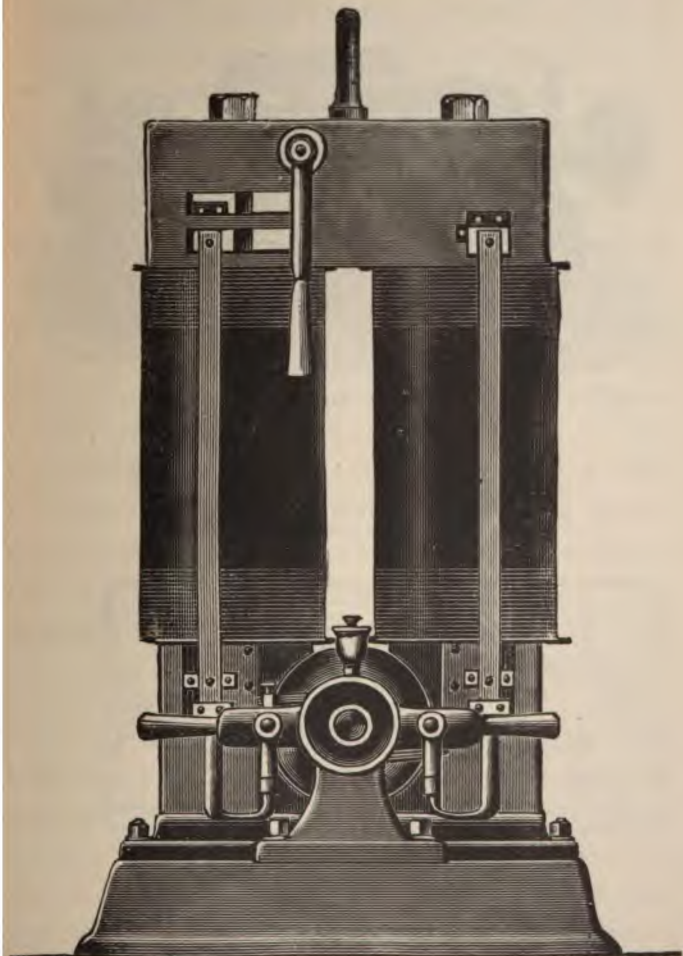

FIG. 65.—IMMISCH MOTOR.

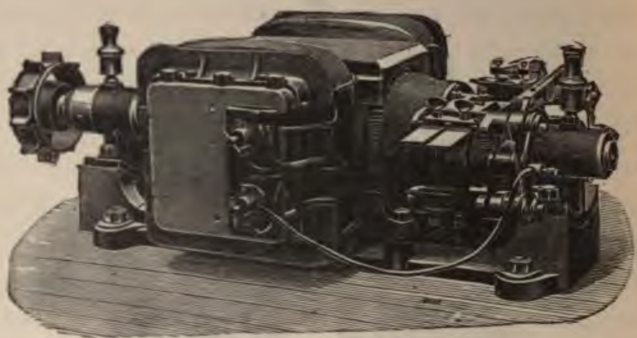

FIG. 66.—LAURENCE, PARIS & SCOTT MOTOR.

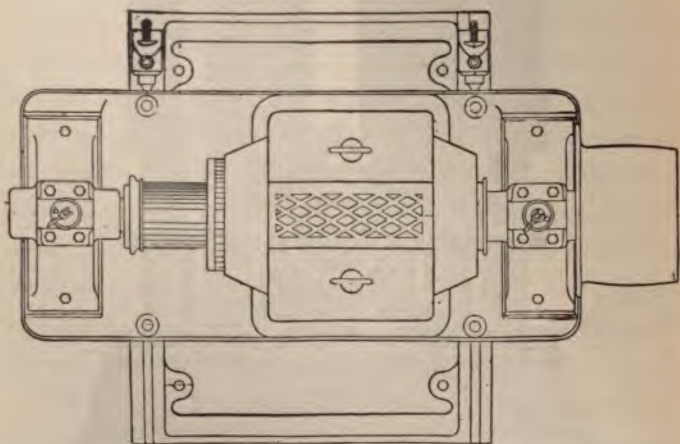

FIG. 67.—ELWELL-PARKER TRAMCAR MOTOR.

nating currents to the working of electric motors, as a great deal of power is wasted. Perhaps the most successful adaptation is to be found in a motor constructed precisely on the lines of Mordey's alternating dynamo, figured and described in § 22.

First in the list of efficient motors may be mentioned the *Immisch*, closely resembling in general features the Manchester dynamo. This is represented in Figure 65. Another form, due to Messrs. Laurence, Paris & Scott, is illustrated in Figure 66. Messrs. Elwell & Parker's motor for tramcars, furnished with four field-magnets, two of which are so wound as to produce a north pole above, while the lower two produce a south pole below, forms our 67th illustration. The *Goolden* motor, constructed specially for the propulsion of electric launches, is shown in Figure 68. The *Reckenzaun* motor with armature of the Pacinotti type is also adapted to tramcars and launches, and is illustrated in Figure 69.

Among the smaller motors adapted for light work, such as dental engines and light sewing-machines, may be mentioned the *Griscom*, of which Figure 70 gives a good idea. In this ingenious little motor the field-magnets consist of a short iron tube the two opposite portions of which are wound with wire in such a direction as to produce opposite magnetic

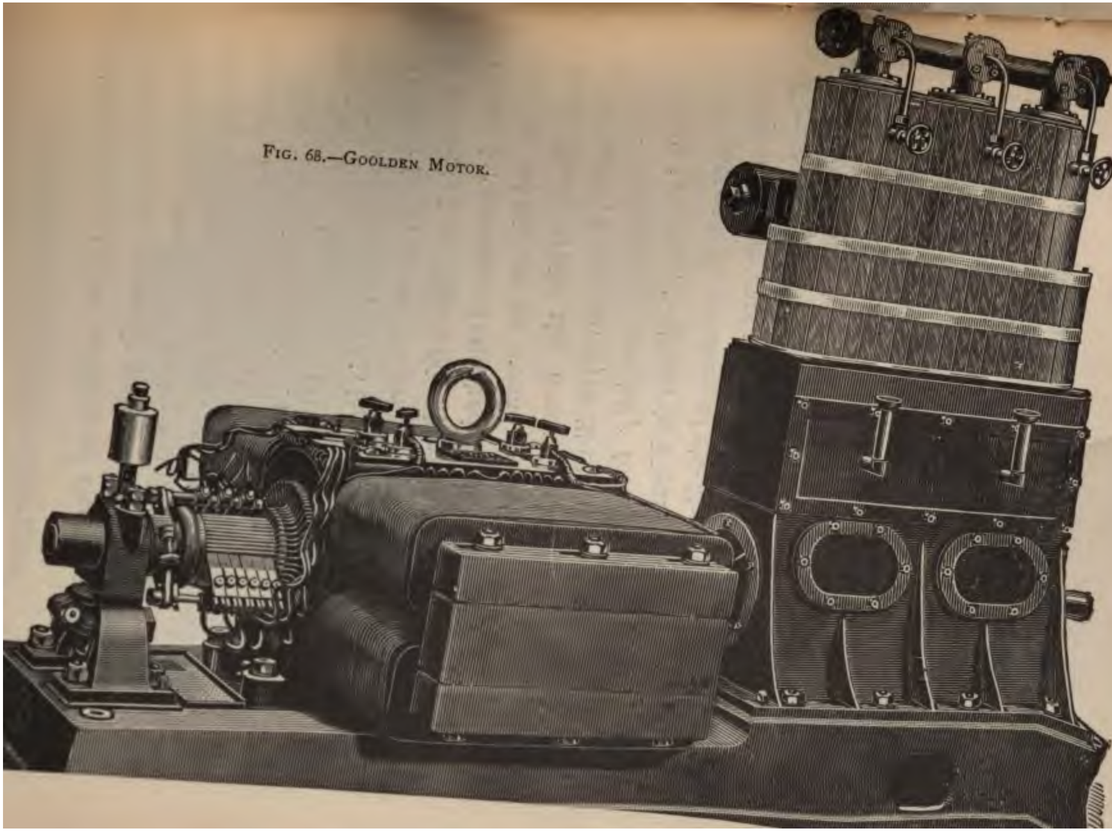

FIG. 68.—GOOLDEN MOTOR.

poles on the two bare portions, and in the interior of this ring rotates the armature. Messrs. Cuttriss of

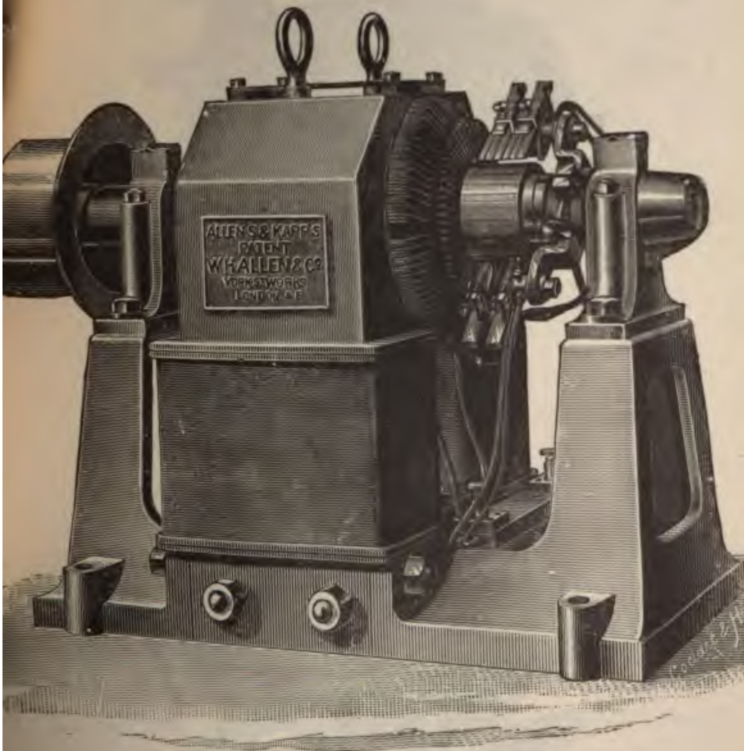

FIG. 69.—RECKENZAUN MOTOR.

Leeds are the inventors of the very compact little motor shown in Figure 71, and have also modified

FIG. 70.—GRISCOM MOTOR.

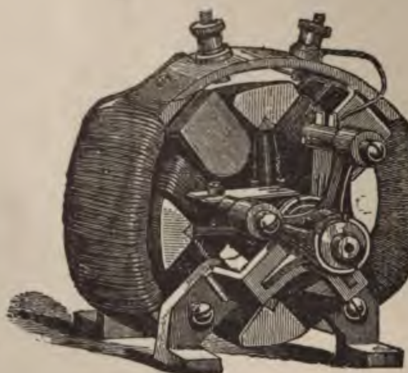

FIG. 71.—CUTTRISS MOTOR.

the *Simplex* motor, previously described, until it has assumed the shape represented in Figure 72.

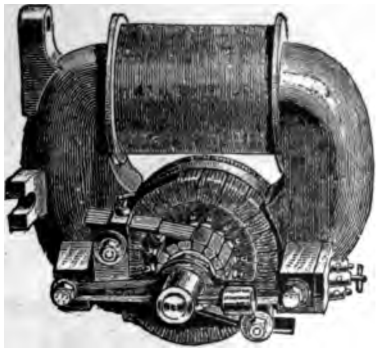

Fig. 72.—Ring Cuttriss Motor.

Inventors in the United States have not been backward in designing neat and substantial little motors for domestic purposes; and our illustration in Figure 73 will give a good idea of the sewing-machine motor constructed by the C. & C. Electric Motor Company, New York.

61. It must be borne in mind, in making use of these motors, that the power obtainable from them is a function of the voltage and current supplied to them. We have seen before that 746 watts are equal to 1 horse-power; so that for every 746 watts supplied to a motor we may reasonably expect to obtain

that amount of power, minus the loss of conversion, provided that the section of the wire be of sufficient size to carry the current supplied without heating,

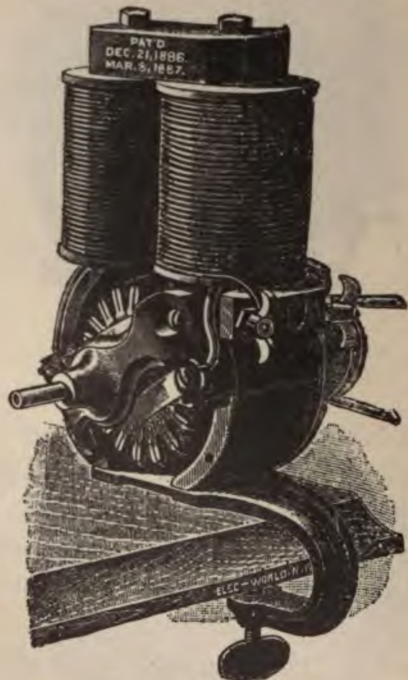

FIG. 73.—C. & C. MOTOR.

and provided also that the mass of iron in the motor be of sufficient size not to become fully saturated with magnetism under the influence of the current supplied. When the magnetic saturation-point of

the iron is reached, the increase in efficiency in the machine is not proportional to the increase in current.

62. There is one error connected with the electric motor into which beginners so often fall that it will be advisable to make special mention of it here, in order to guard the reader against disappointment. The question very often arises, "Can a dynamo be driven by an electric motor which is *itself* actuated by the current from a battery?" The answer to this question is, "Yes, undoubtedly;" but when we come to consider the loss entailed in conversion from electricity into motion, and then back again from motion into electricity, we must add the qualifying sentence, "With a very great loss of power." Let us suppose we have a dynamo which will absorb $\frac{1}{6}$ of a horse-power to drive it, and which when thus driven will give a light equal to 40 candle-power, that is, will light two 60-watt lamps. Now to drive this dynamo the motor must be able to furnish rather more than the $\frac{1}{6}$ horse-power, to allow for friction and slip; and to drive this motor, since small motors waste 40 per cent of the energy put into them, 166 watts must be supplied. In other words, the battery used to drive the motor, which in turn drives the dynamo, would, if connected directly to the lamps, light nearly three instead of only two.

Besides, except for very short experiments the duration of which does not extend over an hour or so, batteries are eminently unsuitable for the production of power to electric motors: firstly, on account of the great price at which they supply current; and secondly, on account of the difficulty of obtaining a fairly constant current for any considerable length of time. For short experiments, and in cases where cost is not an important consideration, batteries of the chromic-acid type are very convenient and will give good results. Where the motor has to be kept in action for several hours, the double forms of the chromic-acid cell, such as the Fuller, etc., will be found serviceable. But the real future of the electric motor lies in the conversion of energy, chiefly supplied by a dynamo, into motion at points to which the current can be carried either by means of cables or by accumulators. The accumulator renders us special service in this regard, inasmuch as it enables us, so to speak, *to store* the energy set up by a dynamo, and transport it whither we will, for after-conversion into motion. For this reason, the accumulator, in conjunction with a motor, is particularly convenient for driving launches, as well as tramcars on some forms of electric railway.

CHAPTER VII

63. IT will have been noticed (see §§ 16 and 22) that by arranging the commutator of a dynamo in a certain manner it is possible to pick up the currents set up in the armature just as they are generated therein; namely, first in one direction, and then in the opposite. Such machines are termed "alternating dynamos," and their currents "alternating currents." At first glance the advantages in using alternating currents may appear few and problematical; but there are cases in which such alternating currents may render good service. For instance, an arc lamp supplied with an alternating current consumes both its carbons equally, since both carbons are alternately positive and negative; again, the Jablochkoff candle *must* be supplied with an alternating current, otherwise the positive carbon, being more quickly consumed, will

soon be out of the striking distance. But there is another and very important application of the alternate current, and that is the capability which it presents of being supplied at one point at a very high pressure, though small in quantity, and being converted at another point into a current of large quantity at a low pressure.

64. This is effected by means of a *transformer*, which consists essentially in an iron core wrapped round with two distinct coils of insulated wire, one fine and the other coarse. When an alternating current of high tension flows through the fine wire coils of such a transformer, it, without itself passing through the coarse wire coils, sets up a current (also alternate) in these coarse wire coils which bears the same relation to the original current with regard to quantity that the section of the wire in the coarse coils bears to the section of the wire in the fine coils. For example, supposing we have an alternating current of 1 ampère delivered at a pressure of 2000 volts, and we cause this to circulate through the fine wire of a transformer, the ratio of the resistance and coilings of the coarse wire to those of the fine wire being as 1 to 2000, we should get from the coarse wires an alternating current of 2000 ampères at a pressure of 1 volt only. The reader may feel curious to know what advantage

can arise from the use of such a transformer; but a moment's consideration will show him that it would be very costly to carry a current of 2000 ampères for a distance of, say, 1 mile, in consequence of the large size of the conductor required: which if of copper would need to be of 2 square inches in section, and

FIG. 74.—HEDGEHOG TRANSFORMER.

would weigh nearly 30,000 lbs.; whereas a current of 1 ampère, whatever the pressure might be, could easily be carried by a conductor ·025 of an inch in diameter and which would weigh about 75 lbs. only. For this reason the transformer lends itself conveniently to large suppliers of electricity, who, having to distribute

currents over large areas in varying quantities and at different pressures, can do this economically and satisfactorily by means of alternate-current dynamos connected to comparatively thin but well-insulated conductors leading to transformers of given capacity at or near the place where the current will be utilised. Figure 74 is an illustration of a good type of transformer.

CHAPTER VIII

65. HERE we propose to make an application of the knowledge we have acquired respecting the different appliances suitable for the conversion of electricity into light or motion. In installing incandescent lamps for the purpose of illuminating rooms, etc., the first question that will arise is, "What power and what number of lamps will be necessary to illuminate a given space?" As a result of many and careful observations, it has been found that to light a room *brilliantly* there should be a 16-candle-power lamp to every 33 cubic yards of space, or a 20-candle-power lamp to every 40 cubic yards. The following table will give a fairly accurate idea of the number of 10-candle-power lamps which should be used for *ordinary* illumination :—

Dimensions of Room, in Yards.			Number of 10-candle-power Lamps.	Height of Lamps (in Yards) above Floor.
Length.	Width.	Height.		
5·0	5·0	4·0	2 to 3	2·2 to 2·4
6·0	6·0	4·8	5 " 6	2·4 " 2·6
8·2	8·2	5·8	9 " 12	2·7 " 3·1
11·0	11·0	7·5	16 " 20	3·1 " 3·4
13·7	13·7	10·4	25 " 30	3·8 " 4·2
17·5	17·5	13·7	40 " 45	4·4 " 4·8
21·0	21·0	15·4	60 " 70	5·1 " 5·8
24·0	24·0	17·5	100 " 120	6·1 " 6·9

If 16- instead of 10-candle-power lamps be used, three-quarters only of the above number of lamps need be employed; and if 20-candle-power lamps, two-thirds of the above number will suffice to give equal illumination. Arc lamps are not particularly well adapted to the lighting of rooms, unless these latter be very large; on the other hand, they are peculiarly suitable to the illumination of large outdoor spaces, of factories and engineering shops. An arc lamp of 1000 candle-power is sufficient for every 750 to 1000 square yards in cotton-mills, weaving-mills, printing and bookbinding works, and similar establishments. In engineering shops a similar lamp will afford sufficient light for 1500 to 2000 square yards; while in dock-yard and other open spaces a 1000-candle-power arc lamp will illuminate six or seven thousand square yards, and will suffice for from twenty to thirty thousand square

yards in street-lighting. In procuring a dynamo for incandescent lighting, a safe rule will be to let the dynamos have a trifle over the E. M. F. that the lamps are marked with, and to allow 1 ampère for every lamp between 48 and 100 volts, 2 ampères for those below 48, and about ·6 of an ampère for those exceeding the 100 volts. For example, an installation of thirty 16-candle-power lamps of 48 volts, each taking about 1 ampère, will be best served by a shunt- or compound-wound dynamo capable of giving 30 ampères at about 50 volts. With regard to motive power, it will be well to allow 1 horse-power for every ten or twelve such lamps; hence a thirty-light installation will need an engine of 2½ horse-power nominal.

66. Although it is not recommended to light lamps for any length of time by batteries, owing to the great cost, and to the inconvenience and labour attendant upon charging, cleaning, and recharging the batteries, yet circumstances may occur which will render their employment compulsory.

For this reason a few details are supplied with a view to giving the cost, the battery most suitable, etc., in these cases. The only battery which is really serviceable, with the exception of the Grove and the Bunsen (which are objectionable in consequence of the noxious nitrous fumes evolved), is the bichromate or chro-

mic-acid cell. This may be made up in two forms: (*a*) without porous cell, for runs not exceeding 3 hours in duration; (*b*) with porous cell, for runs exceeding 3 hours and extending to 10 or 12 at a stretch. The best form to give to the single-fluid chromic-acid cell is that of a zinc plate about 6″ by 3″ by ⅛″, placed sandwich-fashion between two carbon plates of similar dimensions but rather thicker; the plates being separated from each other by a space of about ⅛ of an inch, and supported by a cross-bar on the top, the two carbon plates being electrically connected by a strip of copper. The containing cells may conveniently be well-glazed round earthenware pots about 6″ by 4″. It is well to have the whole series of plates attached to a frame which can be raised or lowered bodily by means of a windlass, ratchet and pawl, if any number of cells are to be employed. Such cells will cost, if home-made, about $1.25 each. The solution for charging should consist of :—

Chromic acid........................	3 parts
Water..............................	20 "
Sulphuric acid, Sp. Gr. 1·840..........	3 "

Dissolve the chromic acid in the water first, then add the sulphuric acid; lastly add :—

Chlorate of potash....................	½ part

Dissolve and allow to cool before use, as the addition of sulphuric acid makes the liquid hot. Every such cell will give 2 volts, and if too much current be not taken from the cell, say not more than 2 ampères, will run steadily for 3 hours. Hence a battery of 25 such elements will run three 48-volt lamps of 16 candle-power each, taking about 1 ampère each, for 3 consecutive hours; the lamps being in parallel. Thirteen cells will run three 10-candle-power lamps of 25 volts for the same time, and six cells will run three 12-volt 5-c.p. lamps for the same period. Any lamp of lower voltage than this will take a correspondingly larger current, so that at least four cells will be needed to run a single 6-volt lamp. Neglecting the first cost of the battery, which amounts, as we have seen, to about $1.25 per cell, we may take the cost of electric lighting by this means as follows:—

FOR 6-VOLT LAMPS OF 3 CANDLE-POWER, TAKING 2 AMPÈRES.

Charging solution for 4 cells, say 3 quarts:—

1 lb. 2 oz. chromic acid, at 18c. per lb......	$0 21
1 lb. 2 oz. sulphuric acid, at 4c. per lb......	05
3 oz. chlorate of potash, at 18c. per lb......	04
Zinc consumed, say 4 oz., at 8c. per lb......	02
	$0 32

That is to say, 32 cents for 3 hours' light of 3 candle-power, or 3½ cents per candle-power per hour.

FOR THREE 10-CANDLE-POWER LAMPS OF 25 VOLTS.

Charging solution, say 9 quarts................	$2 50
Zinc consumed, 4½ lbs., at 8c. per lb...........	38
	$2 88

That is to say, $2.88 for 3 hours' light of 30 candle-power, or 3⅛ cents per candle-power per hour.

FOR THREE 16-CANDLE-POWER LAMPS OF 48 VOLTS.

Charging solution, 18 quarts..................	$5 00
Zinc consumed, 4½ lbs., at 8c. per lb...........	38
	$5 38

That is to say, $5.38 for 3 hours' light of 48 candle-power, or 3¾ cents per candle-power per hour.

67. We may now consider the case of using small lights for very short intervals, say for half a minute to *a maximum* of two or three minutes at a time. This

is convenient for store-rooms, cupboards, and similar places where a perfectly safe light is required for a few seconds at a time only, to get or replace bottles, materials, etc. Under these circumstances Leclanché cells or dry cells may be used to great advantage, since, if only used occasionally at short intervals during the day or night, such batteries will run from six months to a year without requiring renewal or recharging.* Let us say that we require a 2½-candle-power 4-volt lamp. To work this, six Leclanché cells, quart size, will probably be needed. Six such cells will cost 50 cents each (= $3), and will last, if not more than 10 minutes' light be taken from them in the course of the 24 hours, at least six months, or $182 \cdot 5 \times 10$ minutes = 30 hours, nearly, of 2½ candle-power, or 76 hours of 1 candle-power; hence the cost per candle-power hour will be 4 cents, even if we have to renew the cells entirely. But this will rarely be necessary; in most cases it will be sufficient to wash out the cells, clean the zincs, and recharge with sal-ammoniac solution to ensure another six-months' run.

Of the dry cells at present in the market there is one which, from its staying powers and compactness,

* The dry cells, like the accumulator, can, when spent, be recharged by connecting up the positive pole of the cells to the positive terminal of another battery or dynamo, the negatives being likewise coupled together.

recommends itself particularly for this purpose: we refer to the "*Electric Stores* dry battery." In voltage it compares very favourably with the Gesner, the Burnley, or the Northammer and Grieff's dry cells, while in ampèrage and lasting powers it has proved itself without a rival. The utility of an electric light that will give brilliant illumination for a few minutes at a time for some months must be apparent to every householder. With four cells 6″ by 3″, costing 87½ cents each, a 5- or 6-volt lamp can be lighted well. The Electric Stores Co., who make the E. S. dry battery, furnish a small polished box containing four such cells, which is fitted with a reflector, a 6-volt lamp, and a suitable contact or switch, which sometimes takes the form of a pear-push, and a length of conducting wires inserted in a flexible cord, which can be attached to a bedstead, etc. We give an illustration of this compact little arrangement (Fig. 75).

These batteries are also very suitable for lighting gas by electricity, any of the well-known attachments of the burners being employed in conjunction therewith. For experimental work in lighting, general testing purposes, electro-plating, electrical signalling, bell-work, or telephony, these E. S. dry cells will be found of the greatest convenience. The size mentioned has given in our hands an E. M. F. of 1·5

per cell, with an internal resistance of only ·1875 of an ohm, so that the current on the short circuit is for a short time as high as 8 ampères. The cost of the four

FIG. 75.—ELECTRIC STORES BATTERY.

cells, without the fittings, is $3.75; the light given is nearly 4 candle-power; so that the expense per candle-power hour does not greatly exceed 3½ cents.

68. The reader may feel interested to know what will be the expense of electric lighting by means of the dynamo. This will depend largely upon the motive power employed to drive the dynamo. In places where water-power can be obtained conveniently the water-motor is undoubtedly the cheapest and best form of motor that can be used for driving the dynamo. It would appear that, reckoning 300 working days, 10 hours per diem, the price per horse-power as supplied by water-motors amounts to about \$14. Basing our calculation on this rate, and taking the actual electrical efficiency of the horse-power as being equal to 200 candle-power, this gives $3000 \times 200 = 600{,}000$ candle-power hours for \$14, or less than $\frac{1}{500}$ cent per candle-power per hour. This of course is not reckoning the depreciation of plant or renewal of lamps, which in this particular instance would amount to more than the cost of the light itself. Only those favoured by locality, however, can hope to get their power so cheaply. The next cheapest source of power is the steam-engine.

For the sake of those who are anxious to get at the actual cost of the appliances necessary and the amount expended in producing the light, the following rough estimate of an installation of 200 lamps of 16 candle-power is appended:—

16-horse-power engine and boiler	$1750 00
Dynamo for 200 16-candle-power lamps	600 00
200 incandescence lamps, at 90c. each	180 00
200 holders, at 25c	50 00
200 electroliers, brackets, or pendants, at $1.25	250 00
200 small switches, separate or attached to electroliers	100 00
Fusible plugs or cut-outs, for every 10 lamps, at $1.12½ each	22 50
Fixing electroliers, etc., say $1 per lamp	200 00
Fixing dynamo and engine	25 00
Leads and cables	200 00
Belt for driving dynamo	50 00
Packing	25 00
Total cost of plant	$3452 50

Now let us glance at the maintenance of this installation:—

37½ cents for the 200 lamps per hour working expense, 6 hours a day the year round	$821 25
Renewal of lamps after 1000 hours' light, at 90 cents each	180 00
Interest on electric plant, at 5 per cent	87 50
Depreciation on dynamo, switches, etc., at 10 per cent	77 50
Depreciation on cables, leads, and electroliers, at 3 per cent	25 00
Total cost of maintenance per annum	$1191 25

By dividing this sum by the total number of hours' light, namely, 2190, we get the cost of the light of 200 lamps per hour as 55 cents; dividing this again by 200, the number of lamps, we obtain the cost of one lamp of 16 candle-power per hour as 0·275 cent and $\frac{1}{16}$ of this = 0·0172 of a cent per candle-power per hour. For the sake of comparison, the following estimate of the cost of a similar plant driven by a gas-engine is subjoined.

As the price of gas varies greatly in different places and at different times, let us take the average price at $1 per 1000 cubic feet.

A good gas-engine will consume 20 feet of gas per horse-power per hour; but reckoning 30 feet, a 16-horse-power engine will consume 480 cubic feet, which at $1 is equal to 48 cents nearly. Allowing the large margin of 25 cents an hour for oil, water, interest, and depreciation, we may call the expense for power only 75 cents an hour; hence:—

16 H. P. gas-engine (Stockport or Otto)....	$1750 00
Plant as before..........................	1702 50
Total cost of plant....................	$3452 50

The maintenance of this installation:—

75 cents per hour, for gas, etc., as above, per annum	$1642 50
Renewal of lamps as before	180 00
Interest on electric plant, at 5 per cent	87 50
Depreciation of electrical plant	102 50
Total	$2012 50

Dividing, as before, by 2190 (the total number of hours), we get 75 cents for 1 hour's light; and dividing this again by 200, we get the price of a single lamp of 16 candle-power as 0·375 of a cent, or 0·023 of a cent per candle-power per hour.

69. It must be borne in mind that in using smaller engines, especially in the case of gas-engines, the cost of power will come out greater, so that an installation of only 20 lamps would cost in maintenance nearly double per lamp what the larger one costs. There are now several large companies in London and elsewhere who supply current at the rate of about 14½ cents per Board of Trade unit. The Board of Trade unit is a thousand "watt-hours"—that is to say, any number of ampères multiplied by any number of volts that shall give 1000. A Board of Trade unit will therefore light a lamp of 16 candle-power, taking 1 ampère at 50 volts pressure, for 20 hours, since $50 \times 1 \times 20 = 1000$.

To get an equivalent light from gas of the standard lighting power, namely, 16 candles for every 5 cubic feet of gas burnt per hour, we should require 100 cubic feet; which at an average price of $1 would amount to 10 cents. So that we may say that the cost of electric lighting, at 14½ cents per unit, would be equivalent to gas at $1.50 per 1000 cubic feet, or once and a half the average price of gas.

There are, however, certain advantages connected with electric lighting which really render its use in practice much cheaper: firstly, the air is not vitiated and consequently health is better maintained, and furniture, tapestry, and book-bindings are not injured; secondly, owing to the great ease with which the current can be turned on or off by the mere movement of a switch, the lights can be extinguished whenever a room is left, instead of leaving them burning, as is often done in the case of gas to avoid the trouble and delay in relighting. In a private installation the cost per unit need not exceed 8 cents; in which case the electric light would certainly prove itself the cheaper of the two illuminants.

70. Companies that supply electric light, in order at once to satisfy their customers that the due amount of current has been supplied and to protect themselves from loss, place in view an electricity-meter, by means

of which the amount of current and its pressure can be read off in a manner precisely similar to that in which the gas can be read off in a gas-meter. Fig. 76

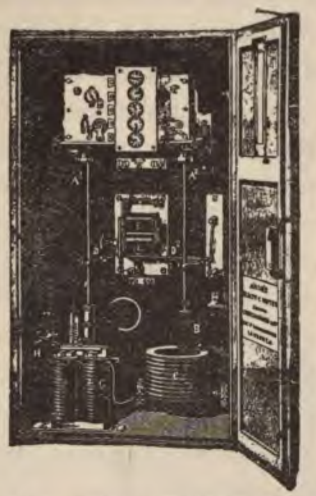

FIG. 76.—DR. ARON'S METER.

illustrates the *Aron* meter. This instrument is specially designed for central lighting stations, as a recorder of the electricity consumed at the various points on the circuit. It is largely used in the various German central lighting stations. With the illustration, which is lettered to correspond with the following description, a fair idea of the instrument can be obtained.

Two pendulums, A, A_1, control two distinct clock-work gears. A is a standard, and oscillates at a regular speed. The second, A_2, has a permanent magnet, B, instead of a weight, and is variable in speed.

The variation is obtained by passing the entire supply of current to be recorded through a solenoid of thick wire, C, placed underneath, but clear of the magnet B. The magnetic influence of this solenoid has an accelerating effect on the pendulum A_2, in direct proportion to the current passed through, producing thus an increased speed in the clockwork gear regulated by this pendulum. The difference of speed between the standard and variable clocks is given in direct ampère-hours by a differential speed-counter gearing on the same principle as a gas-meter index. The slightest alteration in the current passed through is recorded, the whole having to pass through solenoid C. Both pendulums are controlled by catches, D, D_1, which again are controlled by the armature of an electro-magnet, E, placed in a shunt circuit. The electro-magnet G is wound with wire the same size as that on solenoid C, and is placed in series with that solenoid. The armature of the electro-magnet has a spring attached, H, which, when the armature is closed, closes the shunt circuit, causing the controlling magnet, E, to release the pendulums. Immediately

the current ceases to flow, the catches come again into play and hold the pendulums stationary.

A more modern form of meter is that devised by Messrs. Richards, Fig. 77, in which, by means of ap-

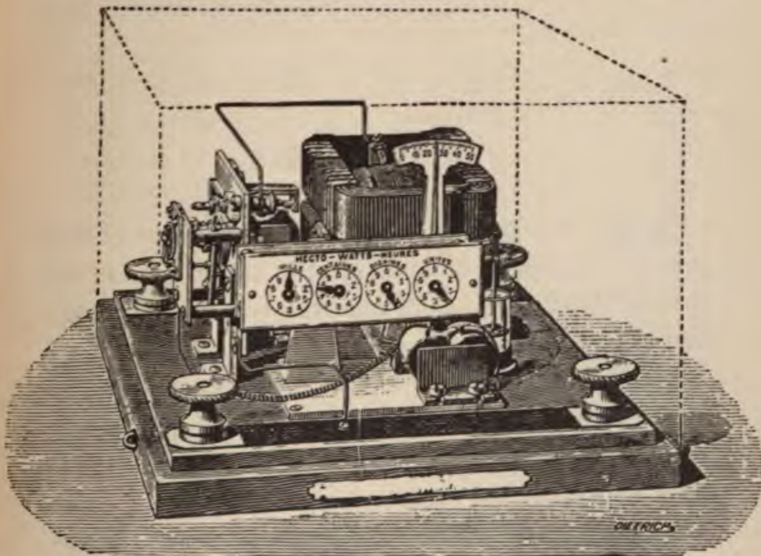

FIG. 77.—RICHARDS METER.

propriate mechanism, the current imparts motion to pointers travelling round four dials on which are indicated in units, tens, hundreds, and thousands the number of Board of Trade units which pass through the meter.

CHAPTER IX

71. WE now pass to the consideration of the cost of power as obtained from an electric motor. As in the case of lighting, we shall take the cost with batteries first. To produce one horse-power we should theoretically require 746 watts, but as few motors return as power more than 80 per cent of the energy put into them as electricity, we must count upon supplying at least 820 watts for each horse-power to be evolved. This proportion will be increased in small motors, which waste more energy, and will be less in the larger ones, some of which have an efficiency of nearly 92 per cent. Taking 820 watts as our standard, it will be found convenient to use a high voltage and a small current when using batteries; since if a large current be taken from a battery, not only does it run down more *quickly, but it* also wastes power by becoming heated.

It will therefore be well not to let the current exceed 4 ampères. Consequently we should need 103 cells, each having a voltage of 2 volts, = 206, from which we could safely draw off 4 ampères, $= 206 \times 4 = 824$ watts, for about 3 hours, at a cost of :—

Chromic acid, 20 lbs., at 18c. per lb.........	$3 60
Sulphuric acid, 20 lbs., at 4c. per lb........	80
Chlorate of potash, 10 oz., at 18c. per lb....	12
Zinc consumed, 6 lbs.,* at 8c. per lb........	48
	$5 00

for 3 hours' run, or $1.67 per horse-power per hour. It is possible to have a cheaper battery than the chromic acid—say, for instance, a modified Bunsen, in which a mixture of nitrate of soda and sulphuric acid is used instead of the nitric acid in the carbon compartment. The cost of running such a battery for 3 hours would not exceed $2, or 67 cents per horse-power per hour. Owing, however, to the evolution of nitrous fumes, such a battery could not be used except out-of-doors or under a properly constructed chimney.

72. The cost of converting electricity into motion

* Theoretically 6 oz. would be sufficient : in practice there is great waste local action.

by the intermediary of a dynamo and a motor comes out somewhat as follows :—

Cost of mechanical horse-power from steam-engine per hour, say	$0 25
Loss in dynamos, 5 per cent	01
Loss of conversion in motor, 20 per cent	04
	$0 30

Say 30 cents per horse-power per hour. This of course is not allowing for loss of power in leads, which has to be reckoned in if the distance between the dynamo and the motor is considerable.

73. The question is often asked as to the relative advantages of alternate and continuous currents for lighting and motor purposes. The answer really resolves itself into a question of which is the cheaper, namely, to use a well-insulated but light conductor to carry a small current of a high E. M. F., or a large conductor not so carefully insulated carrying a large current of low E. M. F. Alternate currents of high E. M. F. are dangerous to life, as any short circuit may lead to very severe, nay, even fatal discharges through the persons of attendants, etc. Alternate currents are also unsuitable for charging accumulators; and motors supplied with currents of this nature are

much more wasteful of power than those which are fed with continuous currents. It would appear also that incandescence lamps fed by alternate currents have a shorter life than those fed by continuous currents. On the other hand, many forms of arc lamp (notably the Jablochkoff) must be supplied with alternating currents to produce the best effects.

THE END

3'